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EXAMINING A DEVICE FOR AIR DISTRIBUTION BY THE INTERACTION OF COUNTER NON-COAXIAL JETS UNDER ALTERNATING MODE

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Вирішено актуальну задачу підвищення ефективності повітророзподілу взаємодією зустрічних неспіввісних струмин для забезпечення нормативних параметрів повітря у приміщеннях. Показано, що для досягнення максимальної ефективності повітророзподілу необхідно подавати повітря струминами, що інтенсивно затухають ще до входу в робочу зону. Показано економічну ефективність використання повітророзподільника порівняно з альтернативними варіантами, наведено питомі показники ефективності повітророзподілу

Ключові слова: повітророзподіл, зустрічні неспіввісні плоскі струмини, швидкість, надлишкова температура, змінний режим

Решена актуальная задача повышения эффективности воздухораспределения взаимодействием встречных несоосных струй для обеспечения нормируемых параметров воздуха в производственных помещениях. Показано, что для достижения максимальной эффективности воздухораспределения необходимо подавать воздух струями, интенсивно затухающими еще до входа в рабочую зону. Показана экономическая эффективность использования воздухораспределителя в сравнении с альтернативными вариантами, приведены удельные показатели эффективности воздухораспределения

Ключевые слова: воздухораспределение, встречные несоосные плоские струи, скорость, избыточная температура, переменный режим

1. Introduction

Modern development of the society is associated with the needs for improving the sanitary and hygienic conditions in production and non-production premises, as well as for saving material and fuel-power resources. Today Ukraine witnesses successful development of such industries as textile manufacturing, microelectronics, computer technologies, production of new materials, tools, jewelry production, etc. In the service area of these industrial premises. maintaining the standard air parameters depends considerably on organisation of air distribution. Working conditions, efficiency and reliability of the equipment operation depend largely on the conditions of air medium of industrial and technological premises, which must be provided by ventilation systems.

In the premises of small volume with dispersed hazardous sources, insignificant heat excess and fixed work places, the solution of this problem becomes more complicated because of the limited distances to the working area at the air supply by vertical jets. In this connection, there is a need for development of new structural solutions for air disribution, which would at the same time provide creation of the necessary microclimate and saving of material and power resources. A problem on the intensification of attenuation of parameters of an air flow due to the interaction of the counter jets has not been sufficiently studied and, as a result, is little used [1, 2].

One of the measures for solving this problem is the use of an air distributor, producing the air flow, formed due to the interaction of oncoming non-coaxial streams. In this case, a considerable air exchange is provided at keeping to standard air velocities in the service zone. Thus, an increase in efficiency of air distribution by the counter non-coaxial jets is an absolutely relevant task.

When choosing a method of air distribution, it is essential to take into account specifics of the premises, their purpose and design features, location and dimensions of heat sources, moisture and harmful gases, the level of requirements for maintenance of design parameters of the microclimate [2, 3]. Small production businesses in Ukraine are widely developing. They usually occupy production premises without distinct requirements for the technological process in terms of maintaining a specific microclimate, with limited space for development of inflowing air jets and with fixed work places. To maintain the air balance in such premises, it is necessary to supply a considerable amount of air [4]. The main task at production cites of this type is to provide standard parameters of air in the working area and to create comfortable conditions for employees. In addition, an important question is energy efficiency of the proposed solution. An essential factor to consider while ventilating the premises of this type is the intensity of attenuation of velocity and temperature of the incoming air flow. Therefore, there is a need for creating new structural solutions for air distributors, which would provide the necessary microclimate in the working area [5–7].

One of the ways of solving this problem is the use of a distributor for providing alternating mode, which supplies two air flows, each of which is characterized by rapid mixing of the inflowing and surrounding air. Such streams include: non-coaxial inflowing jets, moving towards one another and coming into the working area as a resulting jet with standard parameters due to rapid attenuation of velocity and temperature [8].

2. Literature review and problem statement

One of the most complex and essential problems of modern construction is to provide air quality in buildings. People in civil and industrial premises, as well as technological processes in industrial workshops need maintainance of the necessary meteorologial conditions – a particular microclimate. Protecting designs of the buildings secure premises from direct atmospheric influences, but the external protection only is not enough to maintain the necessary conditions inside the premises all the year round. The necessary conditions are created by means of heating, ventilation and air conditioning systems, or, as they may be called collectively microclimate conditioning systems. In confined premises, different conditions are created in terms of temperature and humidity depending on their purpose [2, 9].

The human body has a thermoregulation system and adapts to certain changes in climatic conditions. But this property of the body is limited and, therefore, meteorological parameters in the room have to be quite consistently maintained by the heating, ventilation and air conditioning system at a proper level.

Knowledge of the permissible boundaries of fluctuations of temperature, humidity and air mobility allows us to regulate the use of particular kinds of UPC.

Due to automatic thermoregulation of the body, humans adapt to changes in parameters of the ambient air. However, this thermoregulation appears effective only for slow and small deviations of parameters from the normal ones, necessary for good health. At considerable and rapid deviations of parameters of the air environment, physiological functions of the body, such as thermoregulation, metabolism, functioning of cardio-vascular and nervous systems, etc., are disrupted. In this case, some serious disorders in the human body may be observed [9, 10].

The task of air conditioning is to maintain such parameters of the air medium, which are comfortable for humans.

The principle of operation of the systems with alternating flow rate implies using air flow rate in a system or in its part as controlling influence in order to use rationally the capital investment and the power [10].

Alternation of the air flow rate within the system is the most important and significant feature of the systems with the alternating flow rate. Probably, no other perameter changes the system, conditions of its design and operation to such extent. Along with thermodynamic parameters of the state, air flow rate is the original magnitude for calculation of processes and selection of equipment. Thus, traditional systems with constant efficiency is a partiular case compared to the systems with the alternating flow rate [8, 9].

Research in the premises of both public and industrial buildings indicate the fact that the human thermal sensing is beneficially affected by the alternating stimuli. The alternating mode of inflowing jets involves the creation of a dynamic microclimate and has a positive effect on the thermoregulation of the human organism [10].

A brief description of the alternating temperature mode and the area of its application is as follows: to enhance "training" of the thermoregulation apparatus, to improve health and reduce fatigue of employees, especially if the character of work is monotonous; it is hygienically reasonable in the industrial and technological premises to change one of the parameters, such as temperature or velocity of air motion, i. e., to create an alternating temperature mode.

Technical maintanence of the alternating temperature mode is associated with the use of special air conditioning and ventilation systems. In the premises, it is necessary to stabilize the mean temperature $t_{i.m}$ at alternating thermal loading, mean relative humidity (or moisture content) at alternating moisture loading, besides, to generate temperature fluctuation of inflowing air, at which the desired amplitude and period of temperature fluctuations in the premises will be provided [6, 5].

A conducted analysis showed that at alternating thermal loading, it is expedient to stabilize the mean temperature value $t_{i.m}$ by changing the air flow rate, which is supplied to the premises. Because thermal loading at the alternating mode decreases compared to the estimated value, the heat, cold and electricity consumption decrease respectively compared with the systems of constant efficiency. When using an alternating air flow rate, it should be increased within one half-period, and decreased within the other, retaining an approximately constant value [9].

Selection of a structure of air distribution devices and organization of air distribution play an important role in providing the necessary and comfortable microclimate in the premises of different purposes. When choosing the design of an air distributors, it is important to study the structure and characteristics of turbulent fan jets [2]. In the heat stressed areas, it is appropriate to apply air distributors that use the interaction of jets, which cover a variety of flat and convex surfaces. Inflowing jets interact with convective jets and other air jets in the premises, which must be considered when constructing effective schemes of the air exchange organization for this type of premises [11]. In industrial areas with a monotonous character of work, constant parameters increase fatigue of employees and negatively influence their performance. One of the most effective methods of solving this problem is to create alternating in time parameters, in particular, air velocity and temperature in the working zone of production premises [2, 3, 10].

To determine advantages and disadvantages of methods for supplying inflowing air and those of the existing air distributors, their analysis was conducted [2]. Vortical air distributors (Fig. 1, *a*) form the twisted fan jet, which provides efficient mixing of a jet with the air of the premises and, consequently, rapid equalizing of temperature and velocity in the jet at a low noise level. Air distributors may work both in systems with the constant flow rate and with the alternating one, which will make it possible to provide the alternating microclimate in the premises. However, the disadvantage of these air distributors is their fixed blades, the slope angle of which cannot be changed depending on a season, which at certain moments will not provide the necessary parameters in the premises.

Adjustable vortex air distributors (Fig. 1, *b, c)* [2] have movable blades, which can be operated in the manual mode or by means of an electric drive or a thermostat. That is, these air distributors can be used in areas with alternating thermal mode. In other words, in case when cold air in the warm season and heated air in the cold season may be supplied through the same air distributor. Inflowing air may also be supplied at relatively high values of operating temperature differences. At the outlet of these air distributors, a twisted jet is formed, which provides efficient mixing at the limited range.

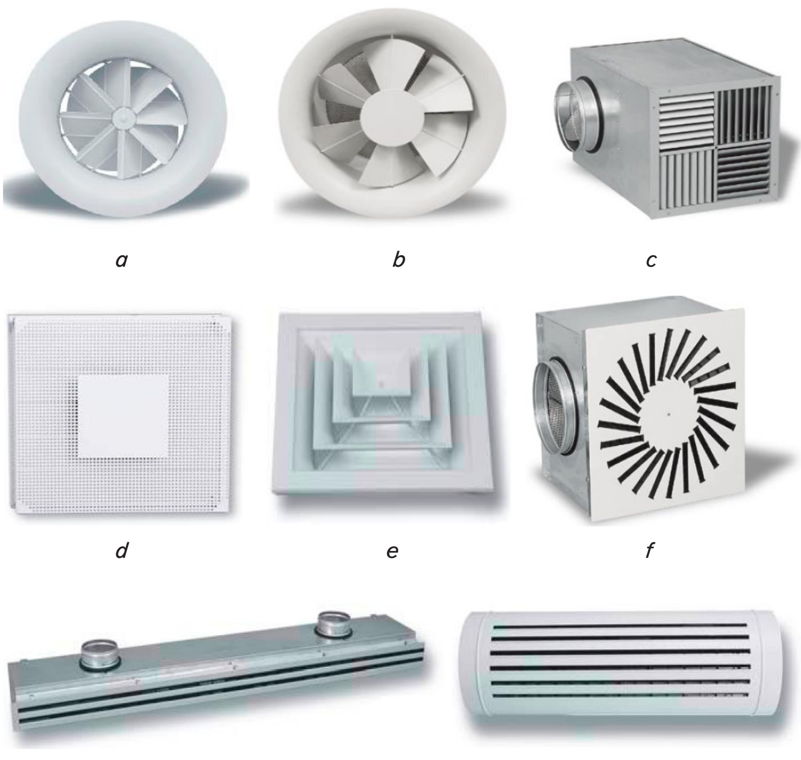


Fig. 1. Air distributors for air supply by the twisted and flat jets: *a* – vortical air distributors; *b, c* – adjustable vortex air distributors; *d–f* – panel air distributors; *g, h* – slot air distributors

When using panel air distributors (Fig. 1, *d–f*), the cooled air distribution through air distributors with perforated panel is used in not very high premises (up to 4 m) to create small air velocities in the working area and a uniform field of temperature and velocity at high air flow rate in the premises. An air distributor with a perforated panel, designed for the air supply into the premises of the height from 2.6 up to 4 m, is meant to be installed in a ceiling grid. The air is distributed horizontally through the slots, forming a flat fan air jet, and vertially through the perforated front panel, forming a conical jet. The air, which passes through a perforated front panel, is mixed with the air of the premises at the outlet of the air distributor. The inflowing air jets, coming out of the slots, eject this mixture, which promotes the uniform distribution of the inflowing air in the premises. Thus, a combined air jet is formed for the distribution of large volumes of the inflowing air. The panel air distributors that form a twisted conical jet are used for the air supply from the height of 3–5 m. Due to twisting of the inflowing jet, there occurs intensive mixing of the air in the premises and a rapid change in the jet parameters. The vortex mode of the air motion is formed by stationary guiding elements that make up the whole with the panel of an air distributor. It is also possible to mount plastic guides in the panel that provide the change in the direction of air supply and jet twisting [2, 9].

The slot air distributors (Fig. 1, *g, h*) may be used in the ventilation and air conditioning systems with the constant and alternating air flow rate. The design of an air distributor implies the possibility of changing the air supply direction, depending on a season. The slot air distributors form a flat jet, which is characterized by a high degree of ejection of the ambient air and the rapid attenuation of the air temperature in the jet. The supply of the chilled air is accompanied by formation of a flat horizontal jet, which spreads out on the ceiling, while the supply of the heated air results in the formation of a flat vertical jet.

After reviewing the air distributors, we may state the expediency of using in the industrial premises of the air distributors with the interaction of the counter non-coaxial jets that would supply the necessary amount of the air to the working area and would provide alternating microclimate parameters and the dynamic microclimate.

3. The aim and tasks of the study

The aim of present work is a scientific substantiation of the air distribution with the interaction of counter non-coaxial jets under alternating mode with the purpose of providing comfortable conditions in the working area of production premises.

To achieve the set goal, the following tasks were to be solved:

– to develop air distributors with the interaction of counter non-coaxial jets with the air supply in the stationary and alternating mode with the possibility of adjusting the air flow rate in the distributing airducts, as well as the methods of their calculation;

– to study experimentally the new proposed air distributing devices that can supply the air to production premises in the stationary and pulsating modes;

– to develop a mathematical model of the process of interaction of counter non-coaxial jets and to define parameters of the resulting air jet depending on the geometrical characteristics of the device;

– to improve the engineering methodology for calculation of basic parameters of the microclimate in the premises and the characteristics of the air distribution device.

4. Materials and methods for examining air distribution by the interaction of counter non-coaxial jets under alternating mode

4. 1. A design of the device for air distribution by the interaction of counter non-coaxial jets under alternating mode

A design of air distributor with the interaction of counter non-coaxial flat jets was developed and protected by the patent of Ukraine (Fig. 2) [12].

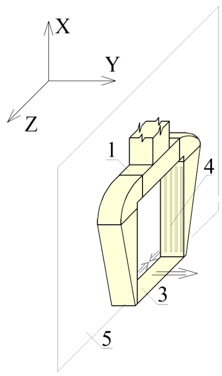


Fig. 2. Air distributor with interaction of counter non-coaxial flat jets: 1 – airduct; 2 – structural part of air distributor; 3 – structural part of air distributor; 4 – inflowing slots b_o=20 mm; 5 – base

In addition, the authors developed a full-scale model of the proposed air distributor for creating dynamic microclimate in the premises using a built-in electric drive Belimo LM24A (Switzerland). It gives an opportunity to change air flow rate in the opposite air ducts, and, consequently, supply the inflowing air in the desired direction depending on the required parameters. This provides the alternating mode in the working area.

Based of the proposed structure of the air distributor, the system with three devices of this kind was proposed to provide the alternating mode in the working zone. Attachment of an actuator, which is controlled from the automation unit, allows us to distribute smoothly the total air flow rate in the airduct between three air distributors. The incoming air flow rate through the air distributors changes smoothly, the period is set by the automation unit, thus creating the alternating microclimate in the working zone, which makes it possible to improve the sanitary and hygienic conditions in the premises.

4. 2. Analytical studies of air distribution by the interaction of counter non-coaxial jets under alternating mode

Formation of the air environment of the premises is affected by the kinetic energy of inflowing jets, contained in large-scale vortices of the inflowing and convective jets. They are split into smaller ones, converting kinetic energy into heat. Turbulent transfer of energy and substances cause the distribution of hazards, temperatures and velocities throughout the whole area and the volume of the premises.

The magnitude of specific kinetic energy E, which is brought by the jet in a unit of time, is attributed to the mass of the air in the volume of the premises:

$$E = \frac{Gv^2}{2V}, \tag{1}$$

where G is the mass air flow rate, kg/s; v – air velocity, m/s; V, m^3 and F, m^2 are the volume and area of the premises, respectively.

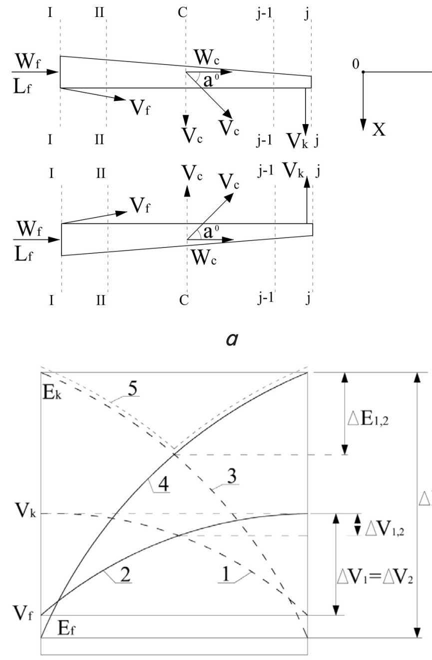


Fig. 3. Change in velocity and specific kinetic energy lengthwise the slots at the outflow of interacting counter jets; *b* – change in specific kinetic energy

Let us consider the air outflow from the slot (Fig. 3). In the cross section of the flat inflowing jet in the airduct, the values of specific kinetic energy for different points are different due to non-uniformity of the velocity of the air outflow. At the beginning of the slot, the flow velocity vector and the longitudinal axis of the channel OZ are nearly parallel, while at the end of the channel, the velocity direction is perpendicular to this axis.

The uniform distribution of kinetic energy in the premises is possible when the algebraic sum of specific energy $E_{п.с}$ of the constituents of inflowing jets in the working area is constant:

$$\Sigma E_f' = \Sigma E_f'' = \ldots = \Sigma E_f^{j-1} < \Sigma E_f^{j}. \tag{2}$$

Let us distinguish the generalized characteristic cross-section C–C (Fig. 3, *a*). The velocity of the outflow v_k (Fig. 3, *b*) from both distribution airducts, which are made in the form of the airducts of uniform distribution, is maximum to the plane of collision of the counter flat jets. At collision, the attenuation of the jet parameters occurs and the velocity of their motion decreases. Curves 3 and 4 of the jet energy (Fig. 3, *b*) are similar to curves 1 and 2 of velocity changes, however, they are characterized by considerable steepness. We can assume that curve 5 of specific energy of the resulting jet will vary more smoothly.

Adding magnitudes of specific energies E_f in appropriate cross-sections, we will obtain the total energy of the jet with distribution close to uniform (Fig. 3, *b*):

$$\left(E_1 + E_2\right)_f' = \left(E_1 + E_2\right)_f'' = \ldots = \left(E_1 + E_2\right)_f^{i-1} = \left(E_1 + E_2\right)_f^{i}. \tag{3}$$

Under the proposed scheme of the jets interaction, the resulting inflowing jet with new aerodynamic characteristics is formed. Different directions of velocities of two interacting jets intensify the air motion with mutual damping of their initial energy (Fig. 3, *b*) [2, 8].

The fact that the axes of the jets in the vertical plane do not coincide allows us to maximize the effect of their interaction with the purpose of converting a pair of rotations of the flow components into progressive motion.

As it may be seen from Fig. 4, the absolute velocity of point M does not depend on its position. Therefore, velocities $\vec{v}$ of all points of the plane of collision of non-coaxial jets at any point of time are geometrically equal to one another. This means that the resulting motion of any point in this plane will be progressive (Fig. 4), the direction of its motion will change into mutually perpendicular. Such character of the air flow motion will positively affect the distribution of velocities in the working area of the premises and provide standard velocities of the air motion.

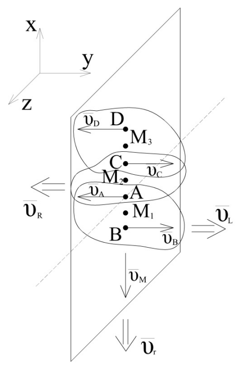


Fig. 4. Velocity vector $\vec{v}_p$ (progressive motion) of the resulting air flow as a result of interaction of counter non-coaxial flat jets (couple of rotation) with velocities $\vec{v}_R$ and $\vec{v}_L$

Appropriate intensification of attenuation of the air flow velocity is achieved when using the effect of the jets interaction. Let us consider their collision at a certain angle α (Fig. 5). To assess the effect of such interaction of flows, we made an assumption: the flow is steady; the interacting jets are weakly non-isothermal; the direction of the resulting flow is determined by the diagonal of the parallelogram, plotted on the vectors of amount of motion $\overrightarrow{m_1 v_1}$ and $\overrightarrow{m_2 v_2}$.

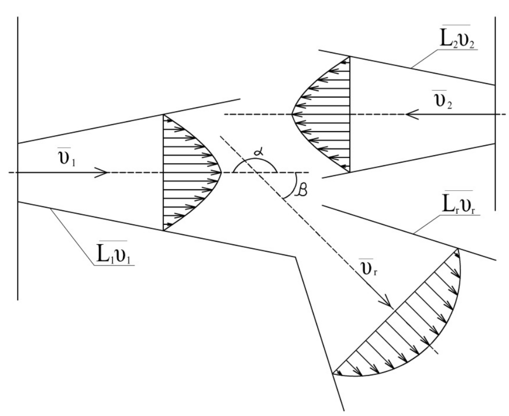


Fig. 5. Schematic of collision of counter non-coaxial jets

According to the law of conservation of momentum:

$$\overrightarrow{m_1 v_1} + \overrightarrow{m_2 v_2} = \overrightarrow{m_r v_r}. \quad (4)$$

Performing the termwise division by time t and density ρ and using the law of cosines, we will move to scalar quantities:

$$\left(L_r \times v_r\right)^2 = \left(L_1 \times v_1\right)^2 + \left(L_2 \times v_2\right)^2 - -2\times\left(L_1 \times v_1\right)\times\left(L_2 \times v_2\right)\times\cos\alpha. \quad (5)$$

Taking into account $L_r = L_1 + L_2$, we find the resulting original velocity v_p:

$$v_r = \frac{\sqrt{(L_1 \times v_1)^2 + (L_2 \times v_2)^2 + 2\times(L_1 \times v_1)\times(L_2 \times v_2)\cos\alpha}}{L_1 + L_2}, \quad (6)$$

where L_1, L_2, m^3/s and v_1, v_2, m/s are respectively the flow rate and mean velocity of the outflowing air jets before their interaction, and v_p is the velocity of the resulting air flow after collision of jets, m/s.

To determine and optimize parameters of an air distributor, the basic characteristic factors are the following: current relative transverse coordinate $\bar{h} = h/H$; relative distance between the axes of the counter flat jets $\bar{l} = l_o/b_o$; relative distance between counter nozzles $\bar{x} = x/X_{a.d}$ and relative air flow rate in the airducts $\bar{L} = L_1/L_2$.

The criterion of optimization is the minimization of air motion velocity v and excess temperature Δt in the working area, as well as attenuation coefficients of the resulting flow m and n.

Thus, we obtain the optimized parameters of the resulting air flow from the air distributor. It is necessary for the optimization of its geometric parameters to maintain comfortable conditions in the premises with inconsiderable heat excess.

4. 3. A study of air distribution by the interaction of counter non-coaxial jets under alternating mode

The authors made the plan of the experiment and gave description of the plant for conducting experimental research of the air distributor using the interaction of counter non-coaxial round (full factor experiment) and flat jets (fractional factor experiment). The process of the research, mathematical tratment of obtained results and their mapping in the form of graphs, nomographs and analytical dependences were described. Basic research was conducted to determine the optimal geometric dimensions of the air distributor, as well as to define the interconnection of characteristics of the air distributor and the resulting flow at the interaction of jets.

The schematic of the experimental research is presented in Fig. 6 [8]. In the presented stand, the air distributor with the interaction of counter non-coaxial jets was explored.

Measurements of air motion velocity V were performed by thermoelectroanemometer testo-405 using the coordinator with the grid of points of 10×10 cm.

The air was supplied using fan 1 through the airducts 3 (a×b=350×350 mm), and was supplied through the inflowing flat slots b_o=20 mm to the structural part of air distributor 6.

To conduct experimental research, a matrix of planning of the 4-factor experiment was compiled, considering the effect of factors interaction, in this case a non-linear mathematical model was accepted. The authors used planning of the fractional factor experiment 2_{IV}^{4-1}, in which the number of the required studies is twice as low as in the full factor experiment [13, 14].

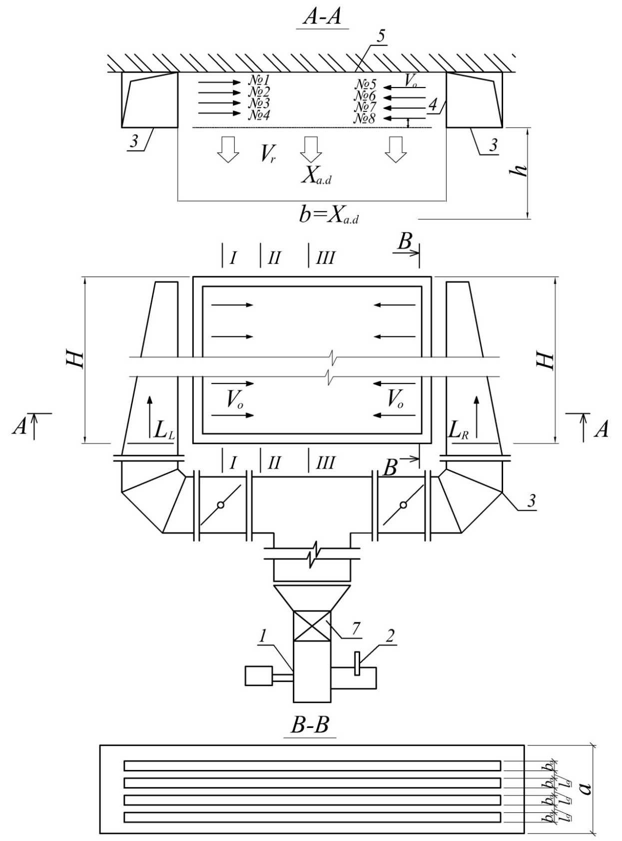


Fig. 6. Schematic of experimental plant for studying the flow, formed by interaction of counter non-coaxial flat jets, where 1 – ventilation unit; 2 – shutter; 3 – airduct of dimensions axb=350×350mm; 4 – inflowing nozzles of width b_o=20 mm; 5 – base; 6 – constructive part of air distributor; 7 – air heater; h – distance to the characteristic plane of velocity fields

We accepted the following magnitudes as input factors:

– x_1=h/H – relative vertical current coordinate;

– x_2=X/$X_{a.d}$ – relative horizontal current coordinate ($X_{a.d}$ is the distance between the distribution airducts);

– x_3=l_o/b_o – relative distance between the axes of the slots;

– x_4=L_L/L_R – ratio of flow rate of the air flows in distribution airducts.

Response functions are:

– $\overline{v}_h = v_h / v_0$ – relative velocity of the air motion in the premises, where v_h is the running velocity of the resulting air flow in the design area of the air distributor;

– $\overline{\Delta t_h} = \Delta t_h / \Delta t_0$ – relative excessive air temperature in the premises, where Δt_h is the running excess temperature of the resulting air flow in the design area of the air distributor, Δt_0 in the original excess temperature (at the outlet of the noozle).

5. Results of research into resulting air flow at the interaction of non-coaxial counter jets

Fig. 7, *a, b* shows some of the results of the conducted experimental research into measuring velocity and excess temperature of the incoming flow according to the matrix of fractional factorial experiment 2_{IV}^{4-1}.

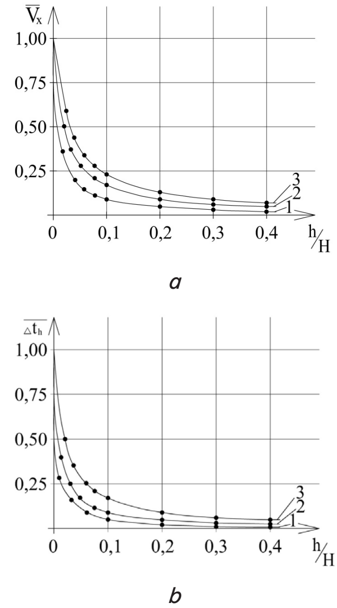


Fig. 7. Graph of dependences of relative velocity $\overline{v}_h$ and relative excess temperature $\overline{\Delta t_h}$ on the current coordinates: h/H and X/$X_{a.d}$: *a* – graph of dependence of relative velocity $\overline{v}_h$; *b* – graph of dependence of relative excess temperature $\overline{\Delta t_h}$. 1 – x_2=x/ $X_{a.d}$=0.5; 2 – x_2=x/ $X_{a.d}$=0.25; 3 – x_2=x/ $X_{a.d}$=0

In this case, relative distance between the axes of the slots was x_3=l_o/b_o=2, and the ratio of flow rates x_4=L_1/L_2=2 (Fig. 7, *a*) and x_4=L_1/L_2=1 (Fig. 7, *b*).

For generalization by the results of experimental research, the correspondent united 4-factor nomographs were plotted.

The nomographs, which are further used in engineering calculations, show the graphic dependence of five magnitudes, one of which is dependent (the left part of the equation), and the others are independent (the right side of the equation), which is mapped by different keys in Fig. 8, *a* to determine relative velocity of the air motion, and in Fig. 8, *b* to determine relative excess temperature in premises $\overline{\Delta t_h}$. Under these conditions, the examples of solution of one direct and four inverse problems were examined [15].

The nomographs, presented in Fig. 8, are approximated by dependences (7), (8):

$$\overline{v}=\frac{0{,}025\dfrac{l}{b_0}-0{,}05\dfrac{x}{X_{a.d}}+0{,}02\dfrac{L_L}{L_R}-0{,}01}{1{,}15\dfrac{h}{H}-0{,}01+0{,}025\dfrac{l}{b_0}-0{,}05\dfrac{x}{X_{a.d}}+0{,}02\dfrac{L_L}{L_R}}; \quad (7)$$

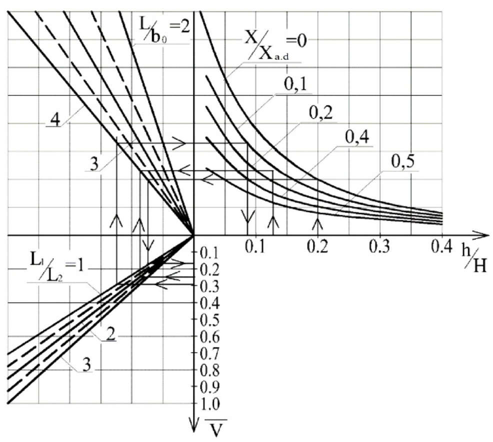
$$\overline{\Delta t_h}=\frac{0{,}02\dfrac{l}{b_0}-0{,}035\dfrac{x}{X_{a.d}}+0{,}015\dfrac{L_L}{L_R}-0{,}007}{1{,}15\dfrac{h}{H}-0{,}01+0{,}025\dfrac{l}{b_0}-0{,}05\dfrac{x}{X_{a.d}}+0{,}02\dfrac{L_L}{L_R}}. \quad (8)$$

The nomographs (Fig. 8) and formulas (7) and (8) show that the increase in magnitudes x/$X_{a.d}$ and h/H leads to a decrease in relative velocity and excess temperature, and an increase in l_o/b_o and L_1/L_2 leads to an increase in relative velocity and excess temperature, which is consistent with the nature of the process.

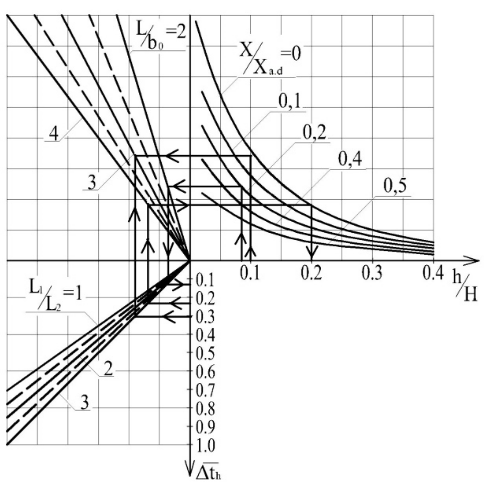
The nomographs, presented in Fig. 9, 10, are approximated by dependences (9), (10):

$$m = 0{,}0225\frac{L_1}{L_2} + \left(0{,}015 + 0{,}0075\frac{L_1}{L_2}\right)\left(5 + \frac{l}{b_0} - 12\frac{x}{X_{a.d}}\right) - 0{,}025, \quad (9)$$

$$n = 0{,}017\frac{L_1}{L_2} + \left(0{,}013 + 0{,}003\frac{L_1}{L_2}\right)\left(5 + \frac{l}{b_0} - 12\frac{x}{X_{a.d}}\right) - 0{,}006. \quad (10)$$



a



b

Fig. 8. Nomographs for determining the relative velocity of air motion $\overline{v}$ and relative excess temperature in premises $\overline{\Delta t_h}$: *a* – nomograph for defining relative velocity of air motion $\overline{v}$; *b* – nomograph for defining relative excess temperature in premises $\overline{\Delta t_h}$

The nomographs (Fig. 9) and (Fig. 10) and formulas (9) and (10) show that an increase in magnitude $x/X_{a.d}$ leads to a decrease in coefficients of velocity attenuation m and temperature attenuation n, and an increase in l_o/b_o and L_L/L_R leads to their increase. Attenuation coefficients are in the range of m=0.05–0.35, n=0.03–0.24 depending on various original conditions. In this case, the Prandtl coefficient of turbulent transport σ

$$\sigma = \frac{n}{m} = 0{,}645 \approx 0{,}67.$$

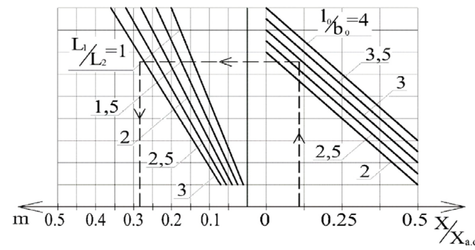


Fig. 9. Nomograph for determining the velocity attenuation coefficient m

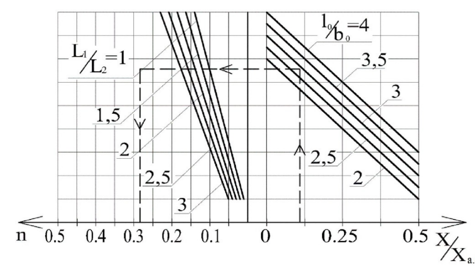


Fig. 10. Nomograph for determining the temperature attenuation coefficient n

Fig. 11 shows a graph of a decrease in the axial velocity of flat and round jets depending on a coordinate

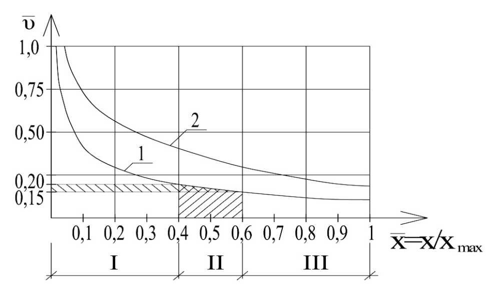


Fig. 11. Determining the jets range: 1 – for flat jets; 2 – for round jets

In Fig. 11, $\overline{X}$ is the relative coordinate, X_{max} is the jet range, m, X is the current coordinate, m; $\overline{\upsilon}$ is the relative jet velocity.

I – $\overline{X} = 0 - 0{,}4$ is the area of expediency of using the interaction effect;

II – $\overline{X} = 0{,}4 - 0{,}6$ is the transition area;

III – $\overline{X} = 0{,}6 - 1{,}0$ is the area of inexpediency of using the interaction effect.

To feel the effect of jets interaction, we accept the assumption that the magnitude of the relative boundary velocity is $\overline{\upsilon} = 0{,}15 - 0{,}20$. So, we determine the boundary relative distance – the so-called maximum range (distance to the area of jets interaction). The transition area is the boundary relative distance and represents the threshold of palpable effect of interaction of non-coaxial jets. The graph shows the parameters of one of the interacting jets. Since the parameters of the other jet are described similarly, the distance between the distribution airducts $X_{a.d}$ (boundary width of the premises) is defined as double magnitude of the distance to the transition area:

$$X_{a.d} = 2\overline{X} \times X_{max} = 2(0,4...0,6)X_{max}. \quad (11)$$

Based on the experimental research, we will define aerodynamic resistance of the proposed air distributors with interaction of the counter non-coaxial jets: ξ=2.44. It was found that the level of noise at jet release from the air distributor does not exceed the permissible limit for this type of premises.

The reliability of the results of experimental research was substantiated by testing the adequacy of the mathematical model by the appropriate Student, Fisher and Kohren criteria at the boundary of the confidence interval $\alpha' = 0,95$.

Based on the conducted experimental research, we presented the technical and economic analysis of using of the air distributor for providing the required parameters of inflowing air to the working area of the premises. The economic effect was estimated by the resulting costs (12)

$$E_i = AC_i - AC_0, \quad (12)$$

where AC_i, AC_0 are the reduced annual costs with reference to three devices, selected for comparison, (perforated panels PN, PVZNKS and PVZNPS), UAH/year, which are determined from expression

$$AC_i = K_i \times E_s + C_i, \quad (13)$$

where K_i is the capital investments, UAH; C_i are the annual operating costs, UAH/year; E_s is the standard coefficient of economic efficiency of capital investments, 1/year (magnitude, inverse to the payback term);

Results of comparative analysis of existing air distributors and the proposed air distributor for the air supply by non-coaxial counter jets are presented in the tabular form (Table 1).

Table 1

Technical and economic indicators of air distributors (for 2016)

No.	Costs	Perforated panels	Air distributors	
			PVZNKS	PVZNPS
1	Cost of the device, €	220	201.42	181.28
2	Cost of mounting works, €	20	15	15
3	Total capital investments by variants, UAH	240	216.42	196.28
4	Costs of consumed energy, €/year	26.78	21.43	19.64
5	Maintenance, €/year	25	20	20
6	Total operational costs, €/year	51.78	41.43	39.64
7	Reduced costs by the variant, €/year	87.78	73.90	69.08

To assess the economic effectiveness of the proposed solution, we compared technical and economic indicators of using perforated ceiling and air distributors PVZNKS and PVZNPS in industrial and technological premises of small dimensions. Conducted calculations showed the savings within 16–22 %. The economic effect of the introduction of such scheme was obtained by reducing both capital and operational costs.

Ventilation system with air distributors PVZNKS and PVZNPS may be used in industrial workshops of other sectors of the industry: microelectronics, computer technologies, production of new materials and tools.

6. Discussion of results of examining the resulting air flow at the interaction of non-coaxial counter jets

Technical and economic comparison of engineering solutions for the air supply to the premises shows the economic impact of up to 18 % compared to the alternative schemes. The effect is obtained by reducing the airduct network, reducing the pressure losses in the system, decreasing electric capacity of the equipment and increasing the velocity at the outlet from the air distributor due to its rapid attenuation before entering the work area.

Thus, the cost-effectiveness of the air distributor with counter non-coaxial jets was proved.

However, this type of air distributors is inappropriate to use in the premises of large volumes, because the range of the resulting air flow decreases due to rapid attenuation of velocity of non-coaxial jets through mutual damping.

7. Conclusions

1. The devices and schemes of air distribution in the industrial and technological premises of small volume with inconsiderable heat excess were improved. The authors proposed air distributors that provide intensive attenuation of velocity and temperature of the air flow, which is formed as a result of interaction of counter non-coaxial jets.

2. The characteristic feature of the designed air distributors is the possibility to change the flow rate, and therefore, the velocity of the resulting air flow. This allows us to create dynamic microclimate in the premises. In addition, the authors determined their optimum structural dimensions, which provide the possibility to maintain the necessary parameters on the resulting air flow, formed by the interaction of the counter non-coaxial jets.

3. A mathematical model of the process of interaction between the counter non-coaxial jets in the premises of small volume with insignificant heat exess was improved and the relevant theoretical dependences were obtained.

4. Based on the improved mathematical model of the resulting flow, formed as a result of interaction of the counter non-coaxial jets and on the results of experimental studies, the expediency of using the interaction of counter non-coaxial flat jets in the premises of small volume with insignificant heat surplus was substantiated.

5. The authors developed and protected by the patent of Ukraine [12] the design of air distributor with the interaction of the counter non-coaxial flat jets PVZNPS, which can supply the air in the steady and alternating modes in industrial and technological premises of small volume with insig-

nificant heat excess. Attenuation coefficients are within the range of m=0.05…035, n=0.03…0.24 depending on various initial conditions, and technical and economic calculations allow us to prove cost-effectiveness up to 18 % compared with the air distributor with round nozzles, and up to 22 % compared to using the perforated panels.

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