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APPLYING A NEURAL NETWORK METHOD TO SEARCH FOR OPTIMAL AIR IONIZATION CONDITIONS

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This paper reports measuring, modeling, and determining the optimized air ionic composition of the air at industrial premises to ensure safe living and working conditions for workers.

The possibility of using saline solutions with different degrees of concentration to increase the number of negative ions in the airspace, as well as the variability of the air flow rate for the process of ionization of the air of industrial premises, has been investigated. Analysis of experimental data revealed that an increase in the concentration of saline solutions leads to a decrease in the release of the number of air ions into the vapor-air space of the room.

It is proved that in order to improve air quality, it is advisable to enable air ionization using an ultrasonic air ion generator and the use of demineralized water. The optimal input parameters established for the ultrasonic installation are: s – distance to the ultrasonic installation, 40 cm; v – airflow rate, 6.00 m/s; and c – concentration of salt water solution, 3.3 %.

The result reported here could be used in the design and development of a control system for an ultrasonic generator of air ions of ventilation systems and microclimate systems in order to create the most comfortable high-quality ionized air at industrial premises.

To find the optimal mode of operation of the ionization process, a representation procedure for a neural network was applied, which was most accurate to determine the optimal parameters for ionizing the airspace of the working room.

Optimization was performed using a Feed Forward Bottle Neck Neural Network (FFBN NN) representation. This approach allows one to determine several optimal conditions for the process under study on the basis of a compromise solution

Keywords: air ionization, air quality, neural network, production facilities, air indicators

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1. Introduction

The concentration of air ions is an important indicator of air quality. Numerous studies of hygienists have shown that air deionization negatively affects the health, well-being, and performance of people. Therefore, in many countries, this indicator is standardized. For example, in the national standard of Germany, the concentration of air ions of both signs in the indoor air cannot be lower than 500 cm^{-3} [1]. The minimum concentration of positive air ions is 400 cm^{-3}, negative – 600 cm^{-3}. The concentration of air ions largely depends on the presence of suspended particles in the air – fine dust and aerosols. In urban environments, in many cases, please give an example from the literature, air is partially or completely deionized, so its use in ventilation systems does not give the desired effect [2]. In addition, metal and polymer air ducts additionally deionize the air. To normalize the air ionic composition of air, artificial ionization is used using high-voltage discharges and ultrasound. But, in order to enable an acceptable distribution of air ions in the volume of the room, it is advisable to determine the rational location of the ionizer, its productivity, and the predominant polarization of ionization. To do this, it is advisable to use modeling the propagation of air ions from the source of ionization, which speeds up and reduces the cost of the project. Correct modeling is possible in the presence of an acceptable mathematical apparatus (functions describing the propagation of air ions) taking into account the generation and recombination of air ions, the deposition of air ions on suspended particles, directed air movement. It is important to choose a modeling method that provides an acceptable error in the distribution of air ions. This will allow somebody to devise a methodology for designing premises with artificial ionization of air and the normative concentration of air ions at all critical points of the room.

2. Literature review and problem statement

Considerable attention is paid to monitoring and normalization of the air ionic composition of air [3]. In enclosed spaces, this is carried out at the expense of full-scale measurements, and in the territories – by the tangential remote method according to the state of vegetation, which is revealed in detail in works [4].

But such methods require large amounts of measurements and significant expenditure of resources and time. In addition, for example, the concentrations of air ions in rooms have a complex dynamics and depend on the operating modes of technological equipment of air conditioning systems, the number of people, and the quality of outdoor air. In [5], the processes of air ion formation are investigated, depending on the presence of chemicals and suspended particles in the air. But such studies are carried out in test rooms with high initial ionization of air, which does not meet the real conditions. Part of the research concerns the purification of air from fine particles and viruses [6], which does not solve the main task – maintaining the concentration of air ions at the standard level. Paper [7] investigated the systems for predicting indoor air quality based on statistical models. But the main task is to enable the necessary air ionic composition of air in its unsatisfactory condition outside the premises and in ventilation systems. This is possible due to the artificial ionization of air. But there is a problem of uniform distribution of air ions from the source of ionization, which is described in detail in [8]. The process of propagation of air ions through directional movement of air is quite complex and ambiguous and depends on many parameters of the environment. Therefore, in order to choose the optimal location of the air ionizer, its operating modes to enable the necessary spatial distribution of air ions in the room, it is advisable to use modeling of such a distribution. Analytical functions for the possibility of modeling the propagation of air ions are given in classical work [9] and take into account all the main parameters such as ion generation, the initial state of air, the concentration of suspended particles, etc. In study [10], the number of optimization parameters was expanded, taking into account the influence of electrostatic fields on the dynamics of air ions. The most common approach to modeling the spread of air ions is CFD modeling, revealed in [11]. The disadvantage of these works is the insufficient visibility of the models and significant discrepancies with the results of full-scale measurements. Relevant is the modeling of various processes using neural networks [12, 13]. The advantage of such tools is that this is a technology that is able to learn how to optimize a particular process. Namely, the determination of optimal conditions for air ionization and the reflection of this process, taking into account the influence of various factors on different initial reactions.

Thus, it is advisable to simulate the propagation of air ions from the source of artificial ionization under different initial conditions and the performance of the air ionizer.

3. The aim and objectives of the study

The aim of the work is to determine the patterns of air ion propagation and the choice of the optimal level of ionization of industrial premises based on the use of the neural network method. This will allow one to correctly configure the monitoring systems and maintain the necessary parameters of the state of the airspace at the premises.

To accomplish the aim, the following tasks have been set:

– to measure the levels of distribution of air ions of the production premises under various factors that can affect the fluctuations in their quantity and composition;

– to determine the optimal conditions for the propagation of air ions using models describing neural connections;

– to develop recommendations for optimization of the air ionic composition of the airspace of the premises.

4. The study materials and methods

To obtain the initial data, the concentration of air ions was measured. Measurement of the concentration of air ions was carried out according to the devised procedure from [14] at the standard device "Sapphire 3K" with a measurement error of 20 %. The concentration of light air ions was defined as the arithmetic mean of 24 readings of the device, continuously fixed for two minutes of measurement. In this case, the random error $\Delta\rho<\delta/3$, satisfying the conditions under which the error in measuring the concentrations of air ions Δ is equal to the system instrumental error δ.

For the artificial generation of air ions, a small-sized ultrasonic air ion generator (UGA) was used, with a power of P_n=10 W, a voltage U_n= 19–24 V DC, a current I_n= 500 mA.

Water was supplied to the UGA membrane using the Mu 108 pump (Zamar, Indonesia): power P_n=2.5 W, maximum water consumption Q=180 dm^3/h, $h$max=0.48 0.55 m. Rotex RAT01-*E* (China) fan with a maximum power $P_{\max}$=20 W was used to supply and distribute air ions into the working space.

Air velocity measurements were carried out using a thermoanemometer TM-4001 (TENMARS ELECTRONICS CO., LTD., Taiwan), air flow rate (volume) 0–9999 mm^3, temperature 20–50 °C, air velocity 0.01–25.00 m/s.

The original study used neural networks (in particular, auto associative neural network (AANN)) as a mapping technique. Multidimensional datasets are difficult to interpret and visualize. The main purpose of mapping is the ability to visualize data by projecting multidimensional data onto a two-dimensional map [15]. AANN are direct communication networks trained to create an approximate mapping of identity between network inputs and outputs through reverse distribution or similar training procedures.

These types of networks can deal with linear and nonlinear correlations between variables. Due to their specific structure, they are also known as Bottle Neck Neural Networks (BN NN) and correspond to a nonlinear PCA.

In the case of the nonlinear projection method, the network is trained to display the vector on itself through a layer of "bottleneck" with fewer nodes than the input (and output) layer. While the neural network is learning, the bottleneck studies low-dimensional data representation. The original study looked at the level of a bottleneck containing two nodes.

The architecture of a Feed Forward Bottle Neck Neural Network (FFBN NN) is shown in Fig. 1. Two neurons in the hidden layer create a corresponding coordinate pair for each input object x_i (h_i={h_i,1, h_i,2}). Thus, each object receives a position on a two-dimensional map. Input objects x_i in the study meet the conditions of establishment in terms of the experiment. In this case, different settings were used for two independent variables. In experimental scheme 1: *c* – concentration – salt water solution (%) and *s* – distances to the ultrasonic unit (cm), and two independent variables (*v* – airflow rate and *s* – distance to the ultrasonic unit (cm)) in experimental scheme 2. As a result, we obtained the distribution of these setting points in a two-dimensional map, respectively, for schemes 1 and 2.

Determining the optimal settings is usually carried out during the planning of the experiment (DOE). The overall goal of DOE is to find out the relationship between the conditions of the experiment (independent variables) and the result of the experiments using a minimum number of experiments.

A detailed discussion of the planning and analysis of industrial experiments is given in [16].

The simplest example is a two-factor complete factor plan at two levels with central points Fig. 2.

The distribution of setting points corresponding to the combination of input parameters was obtained using FFBN NN. Input parameters of experimental scheme 1: *c* – concentration of salt water solution (%) and *s* – distance to the ultrasonic unit (cm); in experimental scheme 2: *v* – airflow rate (m/s) and *s* – distance to the ultrasonic unit (cm). The setting points were distributed in two-dimensional H1/H2 coordinates.

For each setting point, the corresponding output parameters (answers) were obtained. As a response, the concentration of positive (C+) and negative (C–) air ions was used. Contour graphs for (C+) and (C–) were built using the Minitab statistical program. Contour graphs were constructed in the same two-dimensional coordinates H1/H2. Contour graphs were then superimposed on plots containing installation points in the same coordinates.

Thus, the optimization method in the authentic study was based on the imposition of contour graphs containing responses, with plots containing input parameters. The graphs reflect the extreme values and stationary areas in which these points are contained.

The FFBN NN method was used to find the optimal state of air ionization.

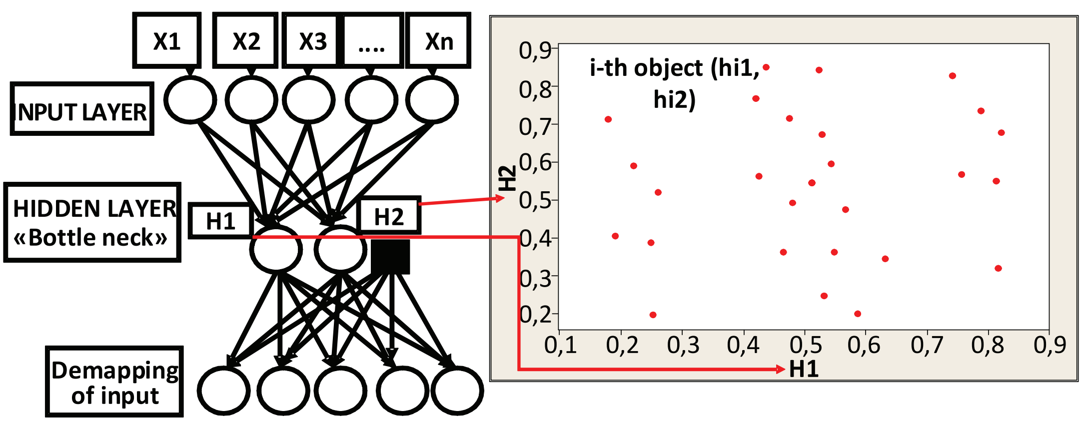
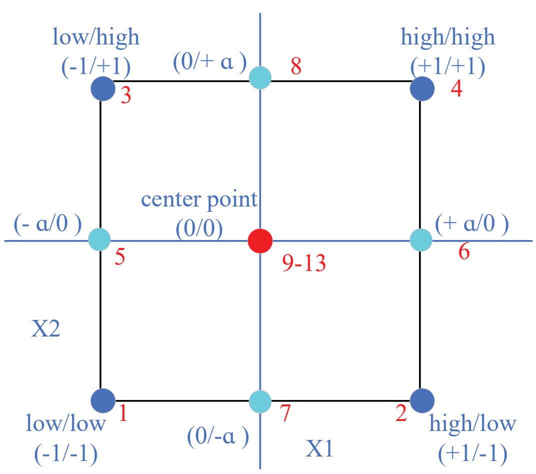


Fig. 1. FFBN NN architecture and the principle of displaying a layer of bottlenecks



Run	X1	X2
1	-1	-1
2	1	-1
3	-1	1
4	1	1
5	-1.41421	0
6	1.41421	0
7	0	-1.41421
8	0	1.41421
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0

Fig. 2. Graphical representation of the 2-factor central composite plan of the experiment at two levels of 4 "cube" points, "center" of the point, and 4 "asterisks" ("axial") points with the matrix of the experiment

5. Results of the study of airspace ionization indicators

5. 1. Experimental measurements of air ion propagation under various factors

To ionize the airspace of working rooms with the most deionized air, it is advisable to use an ultrasonic air ionic generator (UGA) due to the combined effects of water crushing (baloelectric effect, Leonard effect) and ultrasonic cavitation [2].

The research was carried out in order to establish the dynamics of changes in the concentration of air ions depending on the level of water mineralization from 1.1 to 4.4 %. The results are given in Table 1.

Table 1

Change in the concentration of air ions with distance during the sonication of water of varying degrees of mineralization

Factors	Concentration of positive air ions, cm^{-3} (background – n+=1611 cm^{-3})				Concentration of negative air ions, cm^{-3} (background – n–=651 cm^{-3})			
Concentration of salt water solutions / Distance from ultrasonic ionizer, cm	1.1 %	2.2 %	3.3 %	4.4 %	1.1 %	2.2 %	3.3 %	4.4 %
20	1,400	1,270	1,100	1,010	470	410	380	310
30	1,380	1,290	1,080	970	410	390	320	220
40	1,420	1,320	1,120	950	390	340	270	210
50	1,470	1,450	1,230	1,010	370	310	280	230
60	1,500	1,520	1,390	1,070	330	270	270	290

Analysis of the original experimental data (Table 1) shows that the concentration of negative and positive air ions with an increase in water mineralization from 1.1 to 4.4 % is almost halved compared to the background concentration (without sonication – point "0"). With an increase in the distance to 60 cm, the concentration of positive air ions gradually increases almost to background values. A slightly different picture of changes in the concentrations of negative air ions. With a change in the mineralization of water from 1.1 to 3.3 %, there is a sharp decrease in concentrations – from 400 to 270–310 cm^{-3}, but at a concentration of an aqueous solution of 4.4 %, the nature of the changes is almost the same for both negative and positive air ions.

For the uniform distribution of sonicated air ions in working rooms, it is necessary to create air flows, which are regulated by both the speed and direction of the air masses. In this regard, the use of a forced ventilation system is proposed. This decision led to the choice of the next stage of the study, namely investigating the dependence of the change in the concentration of hydro air ions on the influence of the air flow rate in the range from 1 to 8 m/s (Table 2).

Analysis of the obtained values of air ion propagation indicates the identity of the change in the concentrations of negative and positive air ions from changes in the speed of air flow, to which the atmospheric air of industrial premises enters. This can be explained by the fact that when a jet of water with a thickness of ~3 mm is applied to the ultrasonic membrane, the surface tension force changes, which contributes to the purely mechanical breaking of intermolecular hydrogen bonds due to ultrasonic cavitation.

Table 2

Dynamics of the concentration of air ions in the sonication of distilled water with distance from the air flow rate

Factors	Concentration of positive air ions, cm^{-3} (background–n+=170 cm^{-3})				Concentration of negative air ions, cm^{-3} (background–n–=147 cm^{-3})			
Air flow rate / Distance from ultrasonic ionizer, cm	1 m/s	2 m/s	4 m/s	8 m/s	1 m/s	2 m/s	4 m/s	8 m/s
20	590	400	630	410	490	430	550	310
40	390	420	720	450	370	460	720	350
60	380	390	430	490	360	470	700	430
80	370	390	420	470	330	440	650	470
100	350	390	420	460	330	430	620	470
120	350	380	430	460	310	420	590	440
140	360	360	470	450	290	390	590	400

Dynamic equilibrium is established: the more air ions are formed, the more it is recombined. This is especially noticeable at a distance of 40 cm and above the air flow source.

5. 2. Determination of optimal operating conditions using DOE and FFBN NN

During DOE, experimental schemes 1 and 2 were used, given in Tables 3, 4, respectively.

Table 3

Experimental scheme 1 related to the experiment planning matrix used for two independent variables (c – salt water solution concentration (%) and s – distance to the ultrasonic unit (cm))

No.	v	c	v	c	C–	C+
1	0	0	3.30	40.00	306.21	1,110.80
2	–1	–1	2.20	30.00	302.00	1,162.00
3	1	–1	4.40	30.00	241.00	938.00
4	0	1,414	3.30	54.14	272.85	1,335.40
5	1,414	0	4.86	40.00	220.60	923.00
6	0	–1,414	3.30	25.86	371.68	1,032.20
7	–1	1	2.20	50.00	255.14	1,438.60
8	1	1	4.40	50.00	246.06	1,041.20
9	–1,414	0	1.74	40.00	254.20	1,310.90
10	0	0	3.30	40.00	306.21	1,110.80

Table 4

Experimental scheme 2 related to the experiment planning matrix used for two independent variables (v-velocity of air flow (m/s) and s–distance to the ultrasonic setup (cm))

No.	v	c	v	c	C–	C+
1	1	–1	6.00	40.00	695.00	689.00
2	–1	1	2.00	80.00	425.00	353.00
3	1	1	6.00	80.00	588.00	398.00
4	–1,414	0	1.17	60.00	343.00	323.00
5	0	0	4.00	60.00	423.00	358.00
6	0	1,414	4.00	88.28	371.48	281.39
7	1,414	0	6.83	60.00	589.10	480.00
8	0	–1,414	4.00	31.73	493.82	381.09
9	–1	–1	2.00	40.00	437.00	425.00
10	0	0	4.00	60.00	423.00	358.00

In Tables 3, 4 *C* – indicates the concentration of negative air ions, and *C*+ – the concentration of positive air ions.

Independent variables with encoded levels in experimental plans 1 and 2 are given in Tables 5, 6, respectively.

Table 5

Independent variables with encoded levels in the plan of experiment 1

No.	Variables (factors)	Coded levels				
		–1,414	–1	0	+1	+1,414
1	*c* – Salt water solution concentration (%)	1.74	2.20	3.30	4.40	4.86
2	*s* – distance to the ultrasonic unit (cm)	25.86	30.00	40.00	50.00	54.14

Table 6

Independent variables with encoded levels in the plan of experiment 2

No.	Variables (factors)	Coded levels				
		–1,414	–1	0	+1	+1,414
1	*v* – airflow rate (m/s)	1.17	2.00	4.00	6.00	6.83
2	*s* – distance to the ultrasonic unit (cm)	31.72	40.00	60.00	80.00	88.28

The concentration of negative air ions (*C*–) and the concentration of positive air ions (*C*+) were used as answers.

In the original study, an experiment was developed using 2 factors. Therefore, a special architecture of the neural network of error back propagation (2, 2, 2) was used (Fig. 3). The data is fed to the input level with two nodes, and then passed through a hidden level with two nodes (compared to a bottleneck) to a 2-node output level. The number of nodes in the input and output layers corresponds to the number of independent variables. The driving force of the process is to obtain values at the output nodes, most similar to the input variables of the samples, after passing through the bottleneck of the two-node hidden layer. Then the signals in the two hidden nodes are taken as two coordinates for each input object, acting as a two-dimensional projection of samples on the map.

DOE analysis results relating to experimental scheme 1. Fig. 4 shows the distribution of combinations of factors (setting points 1–10) in the 2D map in the coordinates H1/H2.

The combinations overlap with the contour response plots associated with experimental scheme 1, where the following factors were used: *c* – salt water solution concentration (%) and *s* – distance to the ultrasonic unit (cm), where (*a*) is the response surface of the negative concentration (*C*–) and (*b*) is the response surface of the concentration of positive air ions (*C*+).

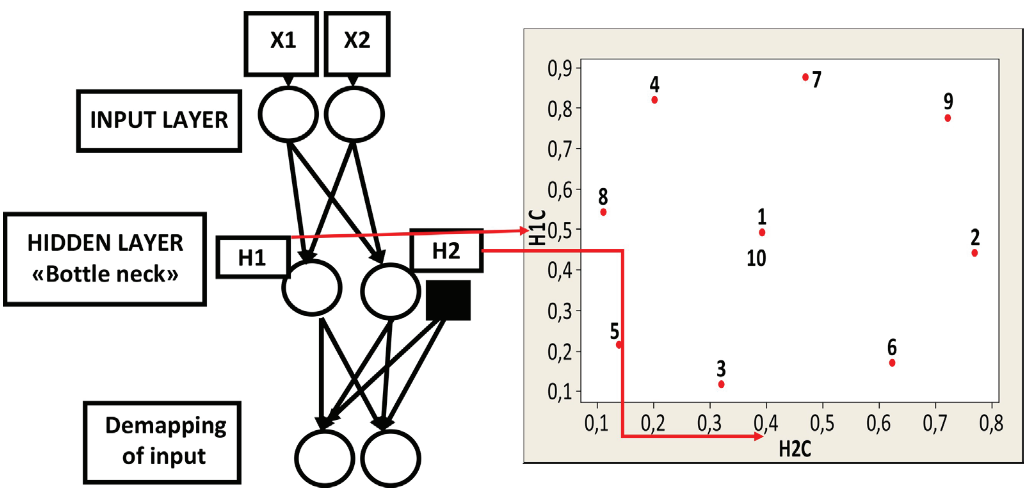
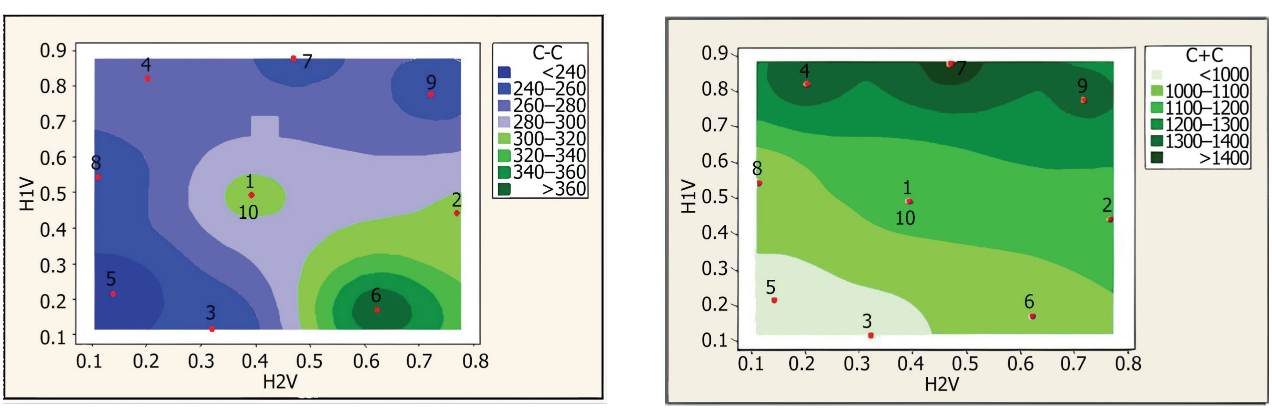


Fig. 3. FFBN NN architecture for a model with 2 factors *X*1 and *X*2 with projection of starting points (1–10) onto a 2D map



a *b*

Fig. 4. Distribution of combinations of factors (setting points 1–10) in a 2D map in the coordinate H1/H2, which overlaps with the contour graphs of the response associated with experimental scheme 1, where the following factors were used: *c* – concentration of salt water solution (%) and *s* – distance to the ultrasonic unit (cm): *a* – response surface of the concentration of negative air ions (*C*–); *b* – positive air ion concentration response surface (*C*+)

5. 3. Devising recommendations for optimization of the air ionic composition of the airspace at premises

Using artificial ionization in the working room, the desired result is to achieve the maximum value of negative and positive ions. But Fig. 4 showed that for the highest value of negative air ions (*C*–) (setting point 6 (dark green) in part *a*)) corresponds to a close to the minimum level of concentration value for positive ions (*C*+) (setting point 6 (light green color) in part *b*)).

The setting point 7 corresponds to the highest positive ion value (*C*+) (setting point 6 (dark green color) in part *b*)), while this setting point in part *a*) corresponds to the dark blue color associated with the closest to the lowest level of negative ion concentration (*C*–).

This means that in this case you need to make a compromise decision.

If we consider the setting point 4, it is obvious that the concentration of negative ions (*C*–) in this case is 272.85 % (average level), and the concentration of positive ions (*C*+) in this case is 1335.40 %.

The setting points 1 and 10 also correspond to the average concentration level of air ions of both polarities. The concentration of negative ions (C–) in this case is 306.21 %, and the concentration of positive ions (*C* +) in this case is 1110.80 %. These points (1 and 10) correspond to the central value (0) in the experiment.

Fig. 4 shows that the highest value of negative air ions (C–) corresponds to the setting point 6 (dark green color), while the smallest value of negative air ions (C–) corresponds to the setting point 5 (dark blue) (Table 7).

The highest value of positive air ions (C+) corresponds to the setting point 7 (dark green), while the smallest value of positive C+ air ions corresponds to the setting points 5 and 3 (light green color) (Table 7).

The minimum level of air ions of both polarities corresponds to the setting point 5 (Table 7).

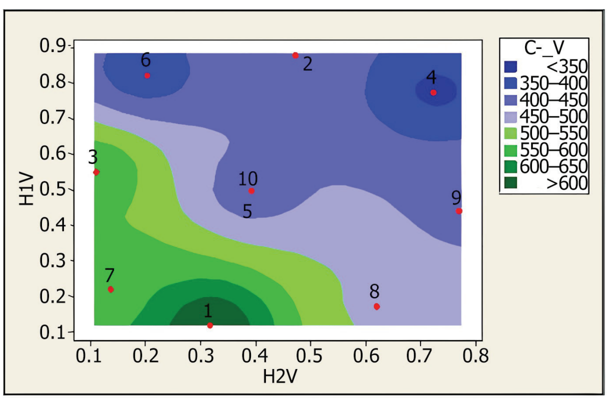
The results of the DOE analysis associated with experimental scheme 2 are shown in Fig. 5.

Fig. 5 shows the distribution of combinations of factors (given points 1–10) in a two-dimensional map in H1/H2 coordinates, overlapping with response contour graphs associated with experimental scheme 2. The following factors were used: *v* – airflow rate and *s* – distance to the ultrasonic unit (cm), where (*a*) is associated with the response=concentration of negative air ions (*C*–) and (*b*) is associated with the response=concentration of positive air ions (*C*+).

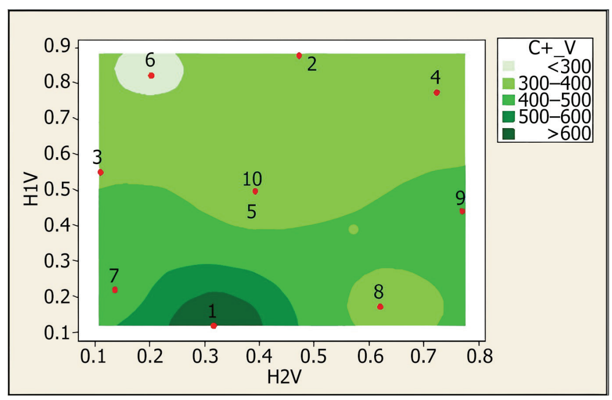
In the case of experimental layout 2 using *v* – air flow rate (m/s), the maximum level of concentration of air ions of both polarities corresponds to the setting point 1 (dark green color in part (*a*) and part (*b*) of Fig. 5 (Table 8).

The highest value of negative air ions (C–) corresponds to the setting point 1 (dark green), while the smallest value of negative air ions (C–) corresponds to the setting point 4 (dark blue).

The distance to the ultrasonic unit (cm) in the case of setting point 1 in experimental scheme 2 is 40 cm. This corresponds to the highest level of concentration (*C*–) and (*C*+). At the same time, this distance corresponds to the average level of concentration of both polarities in experimental scheme 2, where the factor was the concentration of salt in the aqueous solution.



a



b

Fig. 5. Distribution of combinations of factors (setting points 1–10) in a 2D map in H1/H2 coordinates overlapping with a contour response graph related to experimental scheme 2, where the following factors were used: *v* – airflow rate (m/s)) and s – distance to the ultrasonic unit (cm): *a* – response surface of the concentration of negative air ions (C–); *b* – positive air ion concentration response surface (C+)

Table 7

Displaying the maximum and minimum settings and values of answers *C*–, *C*+ in experimental scheme 1

Installation point	Setting the level/value of *c* (%)	Level/*s* (cm)	Concentration of negative *C*– (%)	Concentration of positive *C*+ (%)	Max/min
		C–			
6	0/3.30	–1,414/25.86	371.68	1032.20	Max *C*–
5	+1,414/4.86	0/40.00	220.60	923.00	Min *C*–
		C+			
7	–1/2.20	1/50.00	255.14	1438.60	Max *C*+
5	+1,414/4.86	0/40.00	220.60	923.00	Min *C*+
3	1/4.40	–1/30.00	241.00	938.00	Min *C*+

6. Discussion of results of the study of the optimal air ionic composition of the airspace of the working room

Analysis of the obtained experimental data on the measurement of air ionic composition showed that the use of mineralized water to increase the generation of air ions in the airspace of the room is impractical. The number of air ions is much higher when using ordinary drinking water, as evidenced by the data presented in Table 1. This is due to the absence of any mineral salts and various impurities in it. In addition to the specified in the selected zone, the quality of internal air is improved by minimizing the generation of ozone and nitric oxide.

Provided that demineralized water is used to optimize the generation of air ions to improve the air composition of the working room, the most significant factors are the distance from the air ion generator and the speed of movement of air masses in the room. This is indicated by the data given in Tables 2, 3, the experimental data obtained showed that at a distance of 0.3–0.4 m from the generator, the number of air ions almost doubles.

With the help of the construction of NN, the parameters for monitoring and managing the quality indicators of the air environment in the working space were expanded. This allows one to trace the relationship between the air velocity in the room and the distance to the ultrasonic air ion generator and determine the most optimal parameters for the generation of air ions depending on the distribution of combinations of factors using 2D maps.

Based on the obtained optimums – the maximum values of air ion generation in the airspace – it is determined that the value of air velocity using the directed air flow in the room, which would satisfy the condition of maximum generation of negative air ions, is 6 m/s. In this case, the formation of negative air ions occurs more intensively, as evidenced by 2D maps of the distribution of combinations of factors (Fig. 5). This phenomenon can be used to enable the most comfortable microclimate of industrial premises and improve the sanitary and hygienic standards of the working area.

Thus, on the basis of certain optimums, it can be proposed to use the following parameters of air ion generation to enable the highest quality indicators of air in the working area: s – distance from the working area to the ultrasonic installation – 40 cm, v – indoor air flow rate – 6.00 m/s, subject to the use of demineralized water.

The original results of the DOE analysis to determine the optimal composition of air ions in NN-based airspace have a high level of adequacy. The proposed modes can be used in the design of microclimate systems of operator premises of critical infrastructure facilities, where a significant amount of computer equipment is used. This will improve the quality of air and improve the productivity and concentration of working personnel in rooms with artificial ventilation.

The main limitations of identification of input parameters should be considered a significant increase in the speed of air movement in the room to values of 9–10 m/s. With such dynamic indicators, the accuracy of determining the number of air ions in space using a meter is significantly lost.

Measurements were carried out subject to the normalized temperature conditions of industrial premises without the use of heating systems based on various sources of heating, which can significantly affect the determination of optimal air ionization values under such conditions. Failure to take into account the influence of heating sources in the cold period of the year on the air ionic composition of the air can lead to the fact that the results obtained, even in the selected planning area, will not be entirely true.

7. Conclusions

1. Measuring propagation levels using the neural network mapping technique made it possible to visualize input factors and response surfaces in the same coordinates on a 2D map. The obtained values indicate that the concentration of air ions of both fields with an increase in water mineralization from 1.1 to 4.4 % is almost halved compared to the background concentration. With a change in the mineralization of water from 1.1 to 3.3 %, there is a sharp decrease in concentrations – from 400 to 270–310 cm^{-3}, which causes the use of demineralized water.

The level of propagation of air ions from changes in the speed of air flow indicates an identical dynamics of generation and recombination of air ions of both fields. Dynamic equilibrium is established: the more air ions are formed, the more it is recombined. This is especially noticeable at a distance of 40 cm and above the air flow source. The highest concentration is observed at distances of 0.8–1.0 m from the air ion generator, at an air velocity of 8 m/s.

2. The optimal ionization parameters according to the criterion for achieving the maximum level of negative ions in the airspace for ultrasonic installation are: s – distance to the ultrasonic installation, equal to 40 cm, v – air flow rate equal to 6.00 m/s, and c – the concentration of salt water solution, equal to 0.3 %.

3. Other operating conditions can be taken under compromise decisions:

– to find the parameters of factors (working conditions) that give the “best” feedback;

– to find settings of factors that satisfy the specifications of the work or process;

– to identify new working conditions that give a demonstrated improvement in product quality compared to the quality achieved in the current conditions.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The data will be provided upon reasonable request.

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