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DETERMINING THE DYNAMICS OF ELECTROMAGNETIC FIELDS, AIR IONIZATION, LOW-FREQUENCY SOUND AND THEIR NORMALIZATION IN PREMISES FOR COMPUTER EQUIPMENT

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This paper reports a study into the quantitative values and dynamics of physical factors in premises and workplaces of stationary and portable computers. The factors that are practically not perceived by the senses of operators were investigated. It is established that modern monitors do not generate electromagnetic fields of hygienically significant levels. System units generate electric fields (18–22 V/m) and magnetic fields (220–245 nT) that are approaching the maximum permissible. Sources of uninterruptible power supply and fluorescent lighting systems generate excess magnetic fields (up to 2250 nT and 2300 nT), respectively. The main excessive factor for portable computers is electric fields (up to 9 kV/m), which is the cause of air deionization in the user's zone of stay. It is shown that one system unit in the normative volume of the room (20 m^3) deionizes air (into 100 cm^{-3} positive and 200 cm^{-3} negative). The generation of ions by modernized laser printers and photocopiers of various models (up to 1500 cm^{-3} and 2800 cm^{-3}, respectively) was investigated. The distances at which the ionic composition of the air corresponds to the background values (1.0–1.5 m) were determined. That requires the introduction of artificial air ionization in workplaces of users and a decrease in the levels of electrostatic fields. The spectral composition and amplitudes of magnetic fields of external power supplies of laptop computers were determined. It is shown that the difference in sound levels measured on the scales "Lin" and "A" reaches 24 dB, which indicates a significant impact of infrasound on users. Membrane-type protective panels configured for maximum resonant frequencies of low-frequency sound and infrasound have been proposed

Keywords: personal computer, physical factors, microclimate, electromagnetic field, air ionization, infrasound

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1. Introduction

Computers are an important technical tool in many types of administrative, production, and educational activities. They are the main tool in managing technological processes at industrial enterprises, in air traffic management, the generation and transmission of electricity, etc. Users of this category perform responsible work, the quality and infallibility affect the safety of people, the smooth operation of enterprises, and the quality of products. Therefore, such personnel must be provided with the most favorable working conditions. Significant impact on workers is exerted by such physical factors of the production environment as microclimate, electromagnetic fields, insufficient air ionization, noise. Today, most technological advancements relate to microclimatic conditions and noise. This is because electromagnetic fields, air ionization, low-frequency sound (infrasound) are practically not perceived by the senses and do not cause the need to normalize their performance.

The need to maintain physical factors of the environment in the premises for the operation of computer equipment at a proper (safe) and comfortable level is required by a Pan-European directive [1]. The levels of electromagnetic fields in workplaces of users are regulated by the international standard MPR II [2]. A broader and stricter requirement is the international TCO recommendation standard [3]. However, it is more about generating physical factors, in particular noise, by components of computers. General requirements for the values of physical factors of the environment are regulated by standards [4]. All current standards consider the state of the environment in a static mode. However, its parameters, especially in workplaces of users, may vary depending on external factors (electromagnetic background, transport noise, changes in air composition). A change in environmental indicators can be due to internal factors – the number of simultaneously working computers, the operation of auxiliary equipment, the use of air-cooling systems, the load on the power grid of the building, etc. In addition, there is a rapid change in the range of computer equipment, the emergence of new additional equipment, which makes earlier research in this area obsolete. Therefore, it is a relevant task to study the instantaneous values and dynamics in the quantitative values of critical physical factors at workplaces of users and in the premises for the operation of computer equipment.

2. Literature review and problem statement

Most studies on the physical factors generated by personal computers relate to electromagnetic fields. In work [5], based on measurements, it was concluded that the limit levels of magnetic fields up to 300 Hz were exceeded near the laptop. However, the authors did not clarify the sources of the field, which may be not the components of computers but power supplies, power network. Study [6] shows that the magnetic fields near the surface of a portable computer can be up to 0.5 μT. This result raises very serious doubts due to the lack of components in the portable computer that generate magnetic fields of such levels. In addition, the only recommendation to reduce the impact on the operator is not to keep the computer on his knees. Study [7] measured magnetic fields on different sides of computers but it is recommended that the operator be located at a distance from the computer where the magnetic field level does not exceed 0.4 μT, which exceeds the maximum permissible level [1]. The distribution of ions near computers is investigated in [8]. It is concluded that the presence of the operator does not affect the ionization of air. Changes in the concentration of ions are due to the operation of the fan and the corresponding electrifying of the body. Work [9] modeled the spread of ions from sources of ionization and deionization of air, in particular in the presence of several computerized workplaces. It is shown that the distribution of ions is influenced by the location of equipment, in particular dissecting surfaces.

Modern research on the generation of low-frequency sound and infrasound by computer equipment is quite limited. However, in work [10], it is shown that the noise levels from computer equipment are due to the sound of a low-frequency region of the spectrum, which requires research into the levels of low-frequency sound and infrasound in the rooms where computer equipment is operated. It is required to perform a comprehensive study into the physical factors generated by personal computers of modern models and are not perceived by the senses. In particular, data on the actual values of electromagnetic fields, sources of their generation, and means of normalization are necessary. One needs to study the level and dynamics of air ionization, to find out the productivity of sources of ionization and deionization of air. This will make it possible to devise adequate means of maintaining the concentration of ions of both signs at the regulatory level. Somebody must study the level of low-frequency sound (infrasound) in workplace and the development of means of reducing them to regulatory acceptable levels.

Thus, monitoring the levels of physical factors in the operating rooms with portable and stationary computers will determine their actual values, changes in space and time. as well as generation sources. These data will make it possible to introduce scientifically based measures to normalize and maintain at the regulatory level quantitative values of electromagnetic fields, air ionization, and low-frequency sound.

3. The aim and objectives of the study

The purpose of our study is to determine the dynamics of the intensity of electromagnetic fields, the ionization of air, and low-frequency sound (infrasound) in the premises for the operation of computer equipment. This will provide an opportunity to devise measures to ensure the regulatory conditions of work of users of personal computers.

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

– to carry out field measurements, to determine space-time changes in the levels of physical factors in the premises at workplaces of users of stationary computers and to determine the conditions and means of their normalization;

– to carry out field measurements, determine the space-time changes in the levels of physical factors in the premises and workplaces of users of portable personal computers and determine the conditions and means of their normalization.

4. The study materials and methods

The object of this study is the dynamics of the intensity of electromagnetic fields, air ionization, and low-frequency sound in the premises for the operation of computer equipment.

The main hypothesis of our study assumes the negative impact of computer equipment and auxiliary devices on the values of the physical factors of the environment, their change in space and time.

The premises and workplaces equipped with stationary computers with LCD displays with diagonals of 20, 23, 26 inches were examined. We also examined workplaces with portable computers (notebooks) with screen diagonals of 15 and 17 inches. The influence of peripherals and additional equipment (printers, routers) on the quantitative values of physical factors was determined. All studied equipment was made in 2019–2020, all common models. The levels of electromagnetic fields were measured using Spectran 5035 spectrum analyzer (Germany) with the TCO function (measurement of integral stresses of electric and magnetic fields in the frequency bands of 5 Hz–2 kHz and 2–400 kHz, as defined for computer technology by standards [1, 2]).

Concentrations were measured by the concentration meter of ions of both polarities "Sapphire ZK".

The relative humidity and temperature were measured using the combined device SH601D (China).

The quantitative values of low-frequency sound and infrasound were measured using the SVAN 979 noise meter (SVANTEK, Poland). All equipment was calibrated and used in accordance with the operating instructions.

We measured the quantitative values of physical factors according to the standard TCO procedure [3].

The experiments were conducted in rooms where each computerized workplace accounted for a normative 6 m^2 of area and 20 m^3 of the volume of the room [2].

The air temperature was 21–23 °C; relative humidity, 42–45 %; directional air speed did not exceed 0.1 m/s [4]. Before the start of experiments, wet cleaning was carried out in the premises and the levels of electrostatic fields near all polymer surfaces were measured. Field intensities were lower than the sensitivity of the measuring instrument. The background values of the physical factors studied were measured in the absence of people with disabled technical means. Artificial lighting was turned off.

5. Results of monitoring the quantitative values of physical factors in the premises for the operation of computer equipment

5. 1. Studying the levels of physical factors in the premises for the operation of stationary personal computers

At the first stage, monitors with LCD lighting were tested. Measurements were carried out at a distance of 0.5 m from the device, according to [3]. The results are given in Tables 1–3.

Table 1

Electric field intensity E and magnetic field induction B in front of a 20-inch monitor

Monitor	5–2 kHz		2–400 kHz	
	E, V/m	B, nT	E, V/m	B, nT
1	6	18	1.2	4
2	4	16	1.1	4
3	6	17	1.1	3
4	3	16	1.0	2
5	3	15	1.1	2
Permissible level	25	250	2.5	25

Table 2

Electric field intensity E and magnetic field induction B in front of a 23-inch monitor

Monitor	5–2 kHz		2–400 kHz	
	E, V/m	B, nT	E, V/m	B, nT
1	10	48	1.4	8
2	12	46	1.4	9
3	12	44	1.5	8
4	11	38	1.4	7
5	10	36	1.3	6

Table 3

Electric field intensity E and magnetic field induction B in front of a 26-inch monitor

Monitor	5 Hz–2 kHz		2–400 kHz	
	E, V/m	B, nT	E, V/m	B, nT
1	18	110	1.9	16
2	24	134	2.1	22
3	23	122	1.9	19
4	21	123	2.2	21
5	20	128	2.1	22

Measurements were carried out in real conditions of operation of the equipment. The lighting and other third-party sources of electromagnetic fields were turned off. The maximum basic measurement error did not exceed 3 %.

Our data indicate that the levels of fields do not exceed the maximum permissible values. The trend of increasing field intensity is due to an increase in the power of devices of larger diagonals.

At the second stage, the system units of personal computers were tested. Estimated measurements showed that almost all total electromagnetic fields belong to the frequency range of 5 Hz–2 kHz. This is due to the presence of pulsed power sources with nonlinear volt-ampere characteristics. The results of measurements are given in Table 4.

Table 4

Values of electric and magnetic fields of system units of personal computers in the frequency band of 5 Hz–2 kHz

Power, W	E, V/m	B, nT
450	1–3	28–35
650	4–7	58–84
850	9–11	114–186
1,200	18–22	220–245

Table 4 demonstrates that the values of electromagnetic fields do not exceed the maximum permissible ones but approach them for powerful devices. It should be borne in mind that in some workplaces and premises there are other common sources of fields, for example, sources of uninterruptible power. Our evaluation measurements have shown that the intensity of the electric fields of such devices is insignificant while magnetic – significant. Therefore, the values of the magnetic field were measured (Table 5).

Table 5

Levels of magnetic fields of sources of uninterruptible power in the frequency band of 5 Hz–2 kHz

Power, W	B, nT	
	front side	side
600	110–130	120–150
1,050	750–1,100	710–1,350
1,600	1,850–2,200	1,630–2,250

Significant differences in values are due to differences in device designs and instantaneous current loads during measurements. As one can see from Table 5, the sources of uninterruptible power introduce a great contribution to the electromagnetic situation near a workplace.

Determining the spatial changes in the magnetic field near the devices indicates that it corresponds to the function.

$$B = CL^{-2.7 \div 2.8}, \quad (1)$$

where B is the induction of the magnetic field, L is the distance from the source, C is the constant.

That is, the field decreases quickly enough, and its structure is similar to the field of the magnetic dipole (reducing the field strength is the reverse cubic).

Therefore, such devices should be located at a certain distance from the user. For an electricity source with a power of 1600 W, it is 1.5 m (magnetic field induction becomes one order of magnitude lower than the maximum permissible).

Auxiliary devices (printers, photocopiers, etc.) do not significantly affect the electromagnetic situation at workplaces and indoors. Their electric and magnetic fields are at the limit of background values.

Our study of the effects of lighting systems shows that LED devices generate fields at the limit of sensitivity of the measuring instrument. At the same time, fluorescent lighting systems have a significant impact on the electromagnetic situation. The measurements were carried out at a height of 0.5 m from the floor surface (Table 6).

Table 6

Values of electric and magnetic fields of fluorescent lighting systems at workplaces of users (computers in a hibernation mode)

5 Hz–2 kHz		2–400 kHz	
E, V/m	B, nT	E, V/m	B, nT
19–22	2,100–2,300	10–13	1–3

The levels of the fields of the 5 Hz–2 kHz band, which by magnetic component significantly exceed the maximum permissible levels, and are approaching them by electric. The sources are lamps that are located on the ceiling on the lower floor. This is a systemic phenomenon, so such lighting systems need to be replaced with LEDs.

At workplaces and in the premises for the operation of stationary personal computers, the dynamics of concentrations of ions of both polarities were investigated.

We measured the concentrations of ions in a room with ten identical personal computers. Power, 600 W; monitors with LED backlight. All computers were configured to perform the same task, that is, they work under the same mode. Each computer was given 6 m^2 of space and 20 m^3 of volume. There was no forced ventilation in the room. The measurement start (T=0 h) corresponds to the background value of the concentrations of ions of both signs when the computers are turned off. Table 7 gives average data on each series of 24 measurements.

Table 7

Changes in the concentrations of ions of both polarities (n^-, n^+) depending on the operating time (T) of personal computers

T, hour	n, cm^{-3}	
	n^-	n^+
0	510	580
1	490	550
2	470	440
3	460	370
4	450	380
5	460	370

During measurements, there were no staff in the room. The electrification of surfaces differed within the measurement error. This indicates that the process of air deionization is due to the work of personal computers. In the normative volume, one computer during three hours of operation reduces the concentration of negative ions in the air by about 100 cm^{-3}, positive – by 200 cm^{-3}. After that, the concentrations of ions of both signs stabilize. Control measurements using computers of other models showed similar results (within the measurement error). The result indicates the deionization of air by stationary personal computers to concentrations below regulatory [4].

The identified phenomenon requires the use of artificial air ionization devices in the premises.

However, the impact of technical means common in the premises for the operation of computer equipment is ambiguous.

The concentration of ions at a distance of 0.5 m from working laser printers of different manufacturers was measured (Table 8).

Table 8

Generation of ions by laser printers

Device No.	Number of air ions, cm^{-3}
1	750–920
2	800–950
3	1,200–1,450
4	1,750–1,900
5	1,300–1,500

Significant data discrepancies can be due to different printer performance and different humidity in the premises.

Similar measurements were performed for photocopiers (Table 9).

Table 9

Generation of ions by photocopiers

Photocopier	Number of ions, cm^{-3}
Desktop, A4	440–650
Stationary, A4	1,750–2,100
Stationary MFP, A3	2,500–2,800

Data in Tables 8, 9 data indicate the positive impact of such devices on the ion composition of the air. Patterns regarding their distribution in space and time are easy to calculate based on the functions given in [9]. It should be noted that in printers and photocopiers in the paper feed nodes there are crown discharges that generate ions. However, at the same time, there is a generation of ozone and nitrogen oxides, which can be harmful to people. This phenomenon requires separate research.

The levels of low-frequency sound and infrasound in workplaces and in the operating rooms of stationary personal computers were investigated.

The main source of sound from a personal computer is cooling fans. The total levels of sound of fans of different power and performance were measured (Table 10). Background sound levels did not exceed 5 dBA.

The data show that the noise of fans 4–6 exceeds the norm for these technical means [3].

The spectrum of sound generated by a personal computer was measured (Fig. 1).

Table 10

Basic characteristics of cooling fans in system units

No.	Power, W	Rotation frequency, min^{-1}	Performance, m^3/min	Sound level, dBA
1	1.0	2,400	0.7	28
2	1.7	1,900	1.8	33
3	2.5	3,400	1.3	40
4	6.0	4,300	1.3	50
5	10.0	1,800	1.4	52
6	12.0	3,400	4.5	54

The resulting spectrum indicates that most of the sound generation falls on a low-frequency region. In this case, the levels of infrasound reach 65 dB.

We measured infrasound levels in the room where other physical factors were determined in the presence of ten computers operating in a standard mode (Table 11).

Table 11

Infrasound levels in octave frequency bands in the room with operating stationary personal computers

f, Hz	2	4	8	16
L_{lin}, dB	91	76	75	72

Note: $L_{lin} \approx 74$ *dB,* $L_A \approx 56$ *dBA*

At the same time, the greatest contribution to the overall sound level was given by the frequencies of 0.5–1.0 kHz. A significant difference in the indicators on the scales “Lin” and “A” testifies to the presence of infrasound in the room.

A feature of low-frequency sound and infrasound is low damping with a distance. Therefore, the acoustic situation in the room may be influenced by foreign sources located at long distances from the room. To reduce such influences, the surfaces of the premises should be lined with membrane-type protective panels. The maximum absorption of the elastic wave occurs at a resonant frequency, which is calculated from the ratio.

$$f_r = \frac{1}{2l}\sqrt{\frac{F}{\rho t b}}, \qquad (2)$$

where ρ is the density of the membrane material, *l, b, t* is the length, width, and thickness of the membrane blade.

Resonant frequency is determined by the method of natural measurements, based on the maximum amplitude in octave (tertiary) frequency bands.

5. 2. Investigating the levels of physical factors in the premises for the operation of portable personal computers

Measuring the levels of electromagnetic and magnetic fields of portable computers with screen sizes of 15 and 17 inches in the normative frequency bands of 2–400 kHz showed that they are within background values. The computers were powered by batteries. There was no load on the power grid. Under general operating conditions of computers, the average values of electromagnetic fields in workplace were:

5 Hz–2 kHz – 14–15 V/m, 2–4 kHz – 0.1–0.2 V/m;

magnetic fields:

5 Hz–2 kHz – 82–85 nT, 2–400 kHz – 2–3 nT.

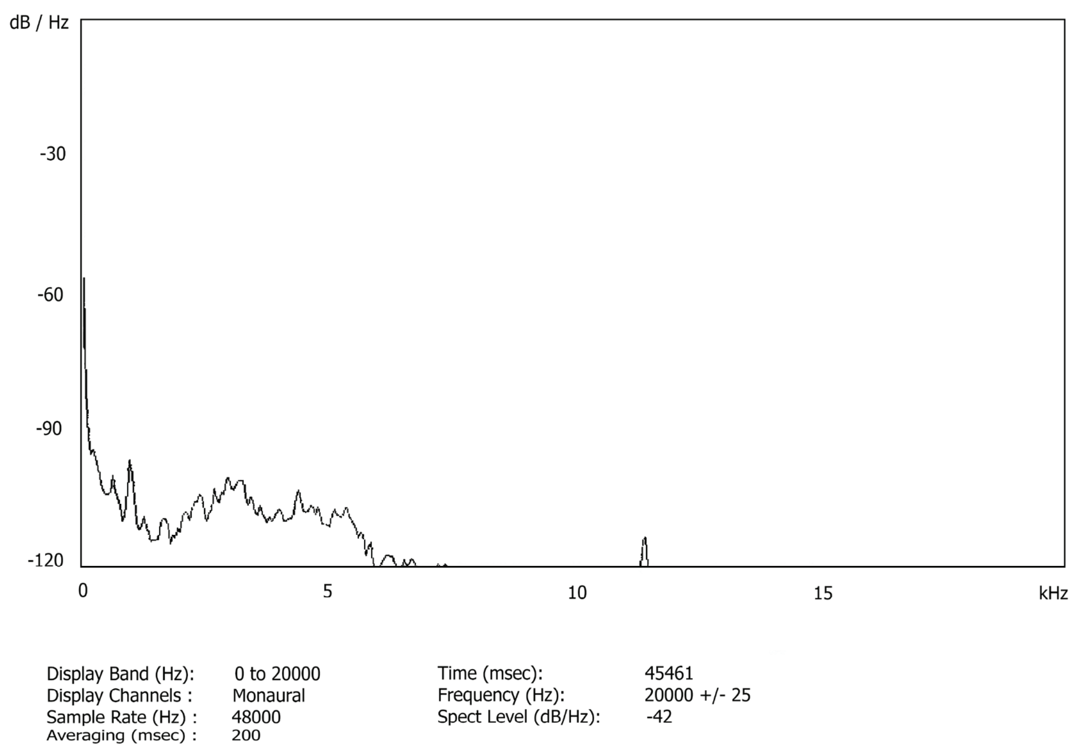


Fig. 1. The spectrum of sound from the system unit of a personal computer

At the same time, there was a tendency to increase the induction of the magnetic field in the low-frequency band with an increase in the load on the power electrical network from auxiliary devices to 220–230 nT.

The spectral composition and amplitudes of the magnetic fields of external power sources of laptop computers were determined. It was clarified that power sources of the same power can have significant differences in the generation of magnetic fields (Fig. 2).

Fig. 2 shows that the first source (Fig. 2, *a*) has amplitudes of the magnetic field at several harmonics of industrial frequency higher than normative.

Repeated experiments did not make it possible to find out the patterns in the generation of magnetic fields of various power sources. Therefore, when operating from a power network, such devices should not be located directly next to the user.

Portable personal computers that operate autonomously (without the use of an external power source) do not contribute to an electromagnetic environment that requires protection measures.

It is important to determine the levels of magnetic fields from foreign sources. The controlled range for personal computers includes an industrial frequency of 50 Hz and its harmonics. It is well known that the presence of electrical and electronic equipment with nonlinear volt-ampere characteristics causes the appearance in the power network of electric currents of harmonics of industrial frequency (mainly the third and multiple three). Such currents generate magnetic fields of the appropriate frequency. Therefore, hygienically significant fields can be generated not by equipment but by the power grid.

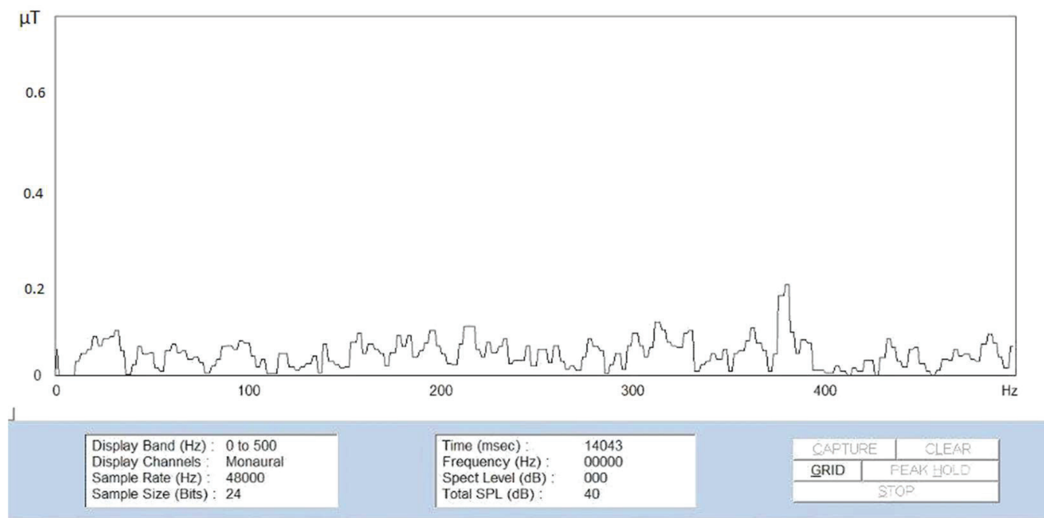
The amplitude-frequency characteristics of magnetic fields in rooms with different numbers of nonlinear electric consumers were measured (Fig. 3).

Thus, the source of excessive magnetic fields in the premises for the operation of computer equipment can be power grids.

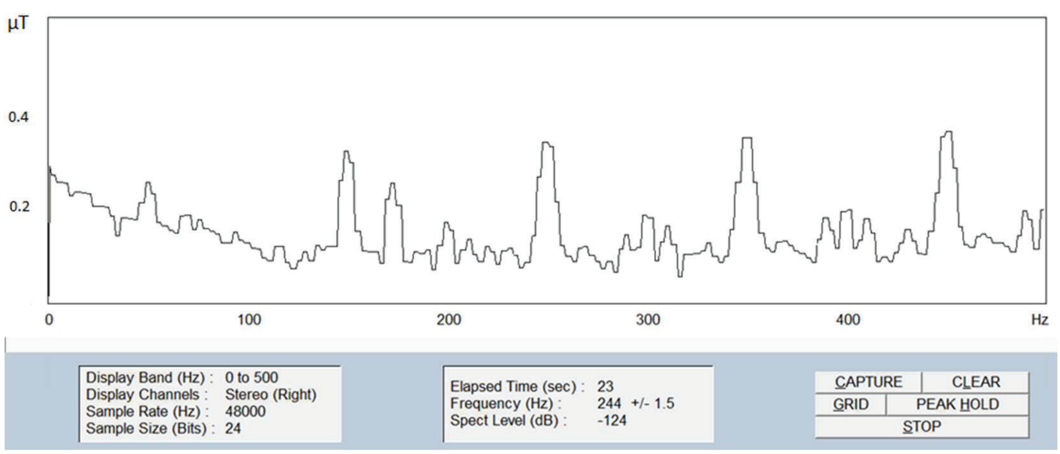
We studied the influence of notebooks on the concentration of ions of both polarities in the air of the premises.

At the first stage, the influence of notebooks on the concentration of ions of both polarities was determined. The measurement was carried out indoors without forced ventilation. There were 6 computers with diagonals of 17-inch screens configured for one task. Each computer had 6 m^2 of space and 20 m^3 of room volume. The concentrations of ions over T=0 correspond to the background, before turning on the computers. There were no staff in the room. The measurement was carried out in workplace.

At the second stage, measurements were performed in a similar way, when operators performed official duties. The data are given in Table 12.

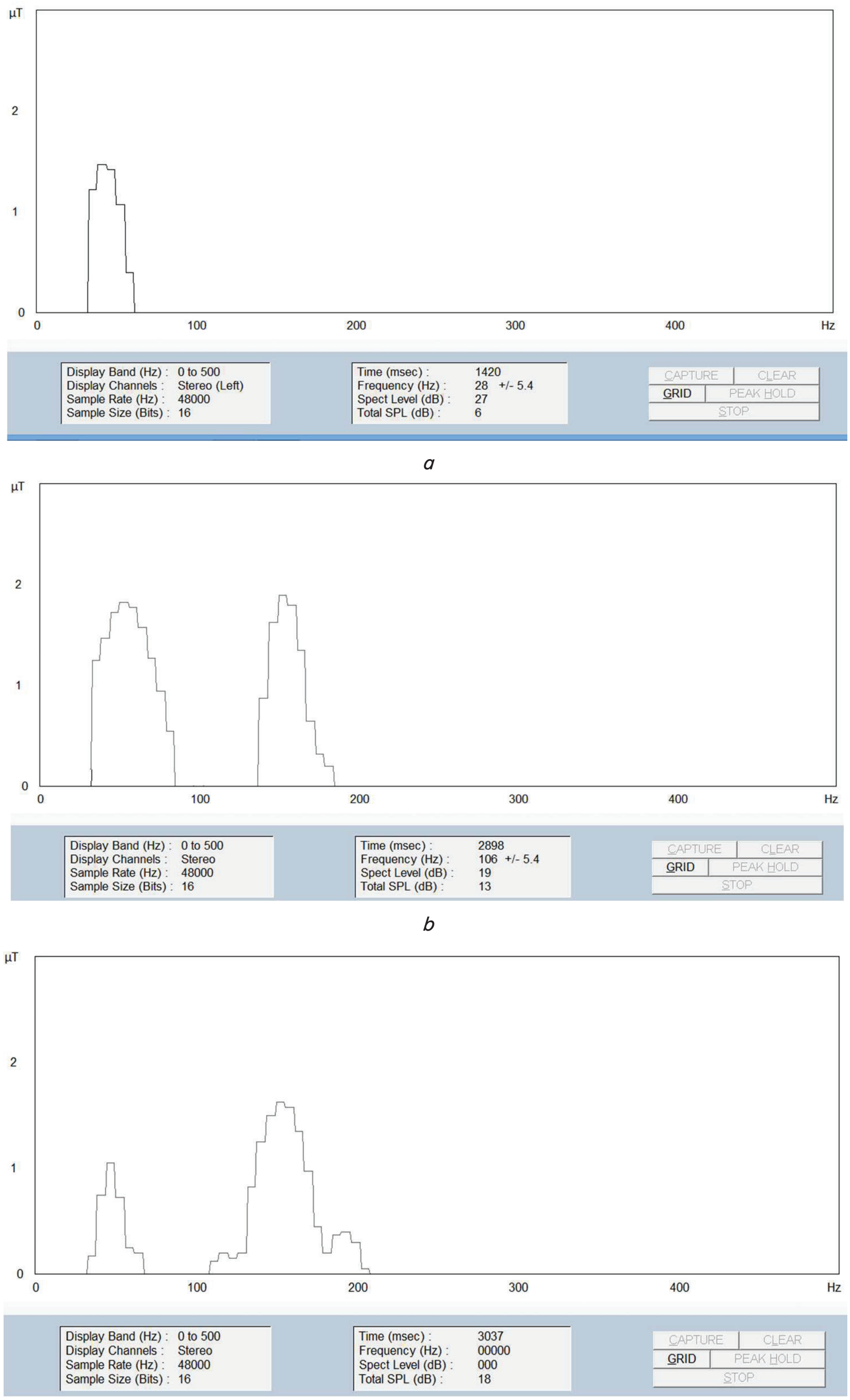


a



b

Fig. 2. Spectral composition of magnetic fields of two power sources of portable computers with a capacity of 330 W: *a* – first source; *b* – second source



c

Fig. 3. Spectral composition of magnetic fields in the premises: *a* — nonlinear loads are less than 10 % of the total electric load, *b* — nonlinear loads make up 15–20 % of the total electric load, *c* — nonlinear loads account for more than 25 % of the total electric load

Data in Table 12 show that the computers themselves do not affect the concentration of ions (differences within the error of the measuring device – 20 %).

When performing work as an operator, the concentrations of ions are sharply reduced.

Our measurements have shown that at distances of 1–1.5 m from workplaces, ion concentrations have background values. That is, air deionization is associated with the presence of operators in workplace. This is possible due to the electrification of surfaces due to the triboelectric effect.

The intensity of electrostatic fields that are formed during operation within 2 hours was measured (Table 13).

Table 12

Dynamics of ion air composition in workplaces of users of personal computers

T, hour	No operators		Operators at work	
	n^{-}, cm^{-3}	n^{+}, cm^{-3}	n^{-}, cm^{-3}	n^{+}, cm^{-3}
0	350	480	530	660
1	340	485	480	640
2	350	470	410	570
3	340	480	320	430

Table 13

Electrostatic field intensity at workplaces of notebook operators

Object	Electrostatic field intensity E, kV/m (distance from object)	Charge sign
Desktop surface	4–8 (1)	–
Notebook display	4–7 (1)	+
Notebook keyboard	9 (1); 5(2); 3(3)	+
The back of the chair	3–6 (1)	–
Armchair seat	6–10 (1)	–

Thus, air deionization occurs due to the deposition of ions in workplace area on electrified surfaces. Neutralization of charges does not occur due to their continuous generation in the process of user operation.

It is possible to avoid this phenomenon in two ways – periodic wet wiping of polymeric surfaces and increasing air humidity to the upper regulatory limit (60 %). In the case of impossibility or ineffectiveness of these measures, it is advisable to use artificial air ionization.

Low-frequency sound and infrasound levels were measured in rooms where notebooks are operated. The measurement was carried out in a room where the background values of these factors were at the limit of sensitivity of the device.

Our measurements have shown that the levels of low-frequency sound and infrasound of one working computer and six running computers are an order of magnitude lower than the maximum permissible level. However, our measurements under real production conditions have shown that due to the high permeability of low-frequency fluctuations, these factors can be significant due to external influences. The typical frequency distribution of infrasound oscillations is given in Table 14.

Table 14

Infrasound levels in octave frequency bands in production facilities

f, Hz	2	4	8	16
L_{lin}, dB	82	78	64	68

Note: $L_{lin} \approx 79$ *dB,* $L_A \approx 55$ *dBA*

The high value of $\Delta = L_{lin} - L_A$ (24 dB) indicates a significant level of infrasound, which has an adverse effect on operators performing responsible functions.

Therefore, in the process of putting the equipment into operation, it is necessary to monitor the acoustic situation due to the influence of third-party sources of low-frequency sound and infrasound. The survey of the premises showed that typical sources of such factors are systems of forced ventilation and pulsations of the heat carrier in heating systems.

6. Discussion of results of studying space-time changes in the intensity of electromagnetic fields, air ionization, and low-frequency sound

Based on the results of our research, a number of discussion issues arose that require consideration and interpretation. It turned out that in workplaces and indoors, the levels of magnetic fields in the controlled range of 5 Hz–2 kHz either approach or exceed the maximum permissible values.

As one can see from Fig. 3, in the presence of 15–20 % of nonlinear consumers, the contribution of a magnetic field with a frequency of 150 Hz is almost the same as the fields of the main frequency, and in the amount of 25 % – exceeds it. In the room for the operation of computer equipment, almost all devices have nonlinear volt-ampere characteristics. And electric currents with a frequency of 150 Hz circulate in the power network and increase the overall levels of magnetic fields. To prevent this phenomenon, it is advisable to equip the building with one of the well-known harmonic suppression systems and industrial frequency interharmonics. At the local level, in a separate room or several premises, to prevent harmonics from entering the power grid, it is possible to apply the connection of technical means through an autotransformer with a transformation coefficient equal to one. In the absence of a galvanic connection with the mains, such a connection is also a means of preventing the leakage of information through power supply networks.

Significant levels of electrostatic fields, in particular at workplaces of users of portable personal computers, in addition to air deionization, cause the directional movement of fine dust, which can get into the eyes of the operator and deionize the air. At the same time, deionization occurs in both polarities. This is due to various signs of surface charges. However, they are generated randomly depending on the materials interacting in the process of work. Therefore, in order to avoid or minimize such a phenomenon, it is advisable to use a bipolar ultrasonic device for ionization and air purification [11]. It will neutralize charges taking into consideration their dominating polarity. Given the significant deionization of air by system units of personal computers, the use of artificial ionization will compensate for it in the desired ratio, taking into consideration the background indicators of atmospheric air.

The most difficult task is to reduce the levels of low-frequency sound and infrasound. This is due to their low spatial damping, that is, the impact on the acoustic environment by distant sources. Existing protective panels are designed for one preferred frequency, which is chosen as resonant. It is advisable to develop and implement protective panels with at least two membranes tuned to the most important frequencies of low-frequency sound and infrasound. This is possible based on field measurements of these indicators in octave or tertiary frequency bands.

Our study has a certain limitation. Taking into consideration the direct and indirect connection of the considered physical factors, it is advisable to develop integral typical models of the propagation of electromagnetic fields, the distribution of concentrations of ions and the acoustic field in the premises for the operation of computer equipment. In the presence of experimental initial data, modeling is advisable to carry out using the conceptual approaches and software given in [12, 13].

The disadvantage of this study is the practical impossibility of taking into consideration and separating external influences on the values of physical factors in workplaces of users of personal computers. Such unforeseen changes are possible due to the switching on of foreign technological equipment in the building or changes in the concentration of ions in atmospheric air due to man-made influences.

The research could be advanced through the use of additional measuring equipment, which will determine the possible impacts on the state of the environment of disturbances of the geomagnetic field, the impact of qualitative composition of building and finishing materials, heating systems, etc.

7. Conclusions

1. It has been established that the electric and magnetic fields of modern monitors in the frequency bands regulated for computer equipment for modern monitors are at the regulatory level. System units of powerful personal computers have electric fields (18–22 V/m) and magnetic fields (220–245 nT), which approach the maximum permissible ones. Sources of uninterruptible power generate magnetic fields of up to 2250 nT, which is significantly higher than the limit values. They should be located at distances of 1.0–1.5 m from the operator. Fluorescent lighting systems generate low-frequency magnetic and electric fields higher than normative (up to 22 V/m, 2300 nT). It is advisable to replace them with LED lamps. It is determined that the system units of personal computers under a stationary mode of operation deionize the air in a normative volume of 20 m^3 (–100 cm^{-3} positive and –200 cm^{-3} negative) per system unit. Laser printers generate 750–1500 cm^{-3} pairs of ions during operation. Photocopiers – 440–2800 cm^{-3}.

2. In the process of working with a notebook, due to the triboelectric effect, the body and other polymeric surfaces accumulate an electrostatic charge. Its intensity reached 9 kV/m. In addition to direct exposure, electrostatic charges deionize the air, which requires the introduction of artificial air ionization. At a distance of 1.0–1.5 m from a workplace, the concentration of ions acquires background values. The normalization of the concentration of ions of both polarities is achieved by increasing the relative humidity of the air to the upper regulatory limit (60 %) or the use of artificial air ionization devices. Our measurement of the noise of cooling fans of system units showed that the sound levels are in the range of 28–54 dBA (depending on the speed and performance). The resulting spectra of the sound of system units indicate that low-frequency sound and infrasound give the greatest contribution to the overall acoustic field. The difference L_{lin}–L_A to 24 dB indicates significant levels of infrasound, which is unfavorable for users. The possibility has been described to apply, for reducing the levels of low-frequency sound and infrasound, panels of membrane type. The calculation of resonant frequency is carried out based on the results of field measurements of sound and infrasound in octave or tertiary frequency bands.

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