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Development Of Ecological Monitoring System Of Environmental Energy Pollution

Marina Vladimirovna Grafkina
Moscow State University of Mechanical Engineering (MAMI) Bolshaya Semenovskaya, 38, Moscow, 107023, Russia

Boris Nikolaevich Nyunin
Moscow State University of Mechanical Engineering (MAMI) Bolshaya Semenovskaya, 38, Moscow, 107023, Russia

Evgeniya Yurevna Sviridova
Moscow State University of Mechanical Engineering (MAMI) Bolshaya Semenovskaya, 38, Moscow, 107023, Russia

Abstract
This paper is devoted to the topical theme-the research of infrasound and electromagnetic fields in the urban environment. Usually people do not fully realize the danger of exposure to these physical factors on the health because it can not sense or feel right. Now the environmental monitoring of low-frequency energy pollution in urban areas is based on the measurement of the amplitude values. Mutual influence of infrasound and electromagnetic fields on living organism is not considered. The scientific literature provides information that noise can affect the electrical characteristics of a person.Taking into account this fact, the authors believe actual definition of synergistic low-frequency impact in urban environments that will allow identify and analyze the total energy contamination on certain areas and to assess adverse effects of infrasound and low-frequency electromagnetic fields on living organisms. An innovative approach to environmental monitoring proposed by the authors in the article, based on the determination of the energy parameters of low-frequency physical fields. Authors theoretically confirm possibility of definition of joint influence of low-frequency electromagnetic and infrasonic fields at their mutual influence on live organisms. The algorithm of definition of an integrated index of power low-frequency unfavourable impact is offered on the basis of measuring complex intensities of infrasound and low-frequency electromagnetic fields. Determination of the integral energy feedback will help to objectively evaluate the impact of electromagnetic fields and infrasound on living organisms, as well as to develop effective measures to improve environmental safety of urban areas.

Keywords: Energy Pollution; Low-Frequency Electromagnetic Field, Infrasound; Energy Effect; Reactive And Active Intensity; Integrated Intensity; Ecological Monitoring; Integral Impact Index.

Introduction

In order to have management information support in the sphere of environmental protection, rational natural resource management, sustainable eco-friendly development of the country and its regions, maintenance of the state data fund on the state of the environment and ecosystems, natural resources, sources of anthropogenic influence in the Russian Federation, the Unified state system of ecological monitoring has been created.

Ecological monitoring includes monitoring of atmospheric air, land, forests, water bodies, objects of wildlife, and subsoil condition and others.

When conducting ecological monitoring the following goals are achieved:

– organization and carrying out of observations of quantitative and qualitative indicators (their totality), which characterize the state of the environment, including the state of the environment in the vicinity of anthropogenic impact sources and influence of these sources on the environment;
– environmental assessment, early detection and development prognosis of negative processes affecting the environment, development of recommendations for the prevention of harmful effects;
– information support of public authorities, local governments, businesses and individuals on the environment;
– formation of state information resources on the state of environment.

The information obtained when carrying out environmental monitoring is used for:

– elaboration of prognosis for socio-economic development of regions and decision-making;
– elaboration of federal programmes in the field of environmental development, special-purpose programmes in the field of environmental protection, investment programs, as well as measures aimed at protecting the environment;
– monitoring in the field of environmental protection (ecological control) and ecological impact assessment.

Development of new approaches to the implementation and evaluation of the comprehensive ecological monitoring results is of particular relevance in identifying actual and potential risks of environmental pollution for public health. Environmental quality criteria determining the health status of population should be a comprehensive indicator of anthropogenic load, which is composed of the most important factors of negative impact. Currently during the ecological monitoring based on environment assessment, two interrelated aspects should underpin it: complex characteristics of the urban environment and the impact of the environment state on human health.

However, current ecological monitoring system doesn't pay enough attention to energy pollution monitoring.

Modern urban environment is characterized not only by constitutive pollution, but also by energy pollution. The main sources of low-frequency electromagnetic fields (EMF) are as follows: power lines, power transformer substations, distribution points of the power supply system, air electric networks, transportation, power systems of ground electric transport, etc. Sources of infrasound in an urban environment – ventilation systems, traffic flows, resonance phenomena in structures of buildings, etc.

Methodology

In order to develop the existing system of ecological monitoring of environment energy parameters it is necessary to implement the following measures:

1. Development and improvement of calculation methods of forecasting and monitoring;
2. Development and improvement of instrumental control methods;
3. Monitoring at all stages of the system life cycle;
4. Assessment of the energy pollution levels in the study area;
5. Creation of a results database for users;
6. Development of protection measures.

Currently, the ecological monitoring for low-frequency electromagnetic and infrasound fields in urban areas includes analysis of amplitude values and is carried out by instrumental and computational methods. The adverse effect of these factors is now determined independently separately without their mutual impact on living organisms. The total energy impact is not determined, and during this ecological monitoring of constitutive pollution there are methods for determining the total (integrated) indicators of negative impact of various harmful substances.

In the scientific literature there is data on negative effects of electromagnetic fields [1]-[12] and infrasound [13] on humans and the environment. Among the registered consequences of electromagnetic radiation – damage to the basic functions of the body, including lesion of the cardiovascular system, digestive system and the development of mental disorders etc. The connection between electromagnetic pollution and the development of malignant tumours and the risk of congenital malformations is observed. Physiological features of infrasound influence on the human body are manifested in a depressing effect on the central nervous, respiratory, endocrine systems.

On the basis of the results analysis of the International Electromagnetic Fields Project, The World Health Organization concluded that there was insufficient research on the results of long-term negative effects of low-level exposure to electromagnetic fields of extremely low frequency (0-100000 Hz) and provided recommendations, including the need for further research to determine the adverse effects on human health and the ways to reduce the levels of EMF exposure in the construction of new facilities.

Publications dedicated to the noise impact on human body electrical characteristics [14],[15] are of particular interest in the context of this work.

Thus, the total energy effect of infrasound and electromagnetic fields on biological objects can be considered as a complex system involving the mutual influence of factors which are not subject to the additive laws. Figure 1 shows the scheme of the simultaneous effect of different sources energy of infrasound and electromagnetic fields on a biological object.

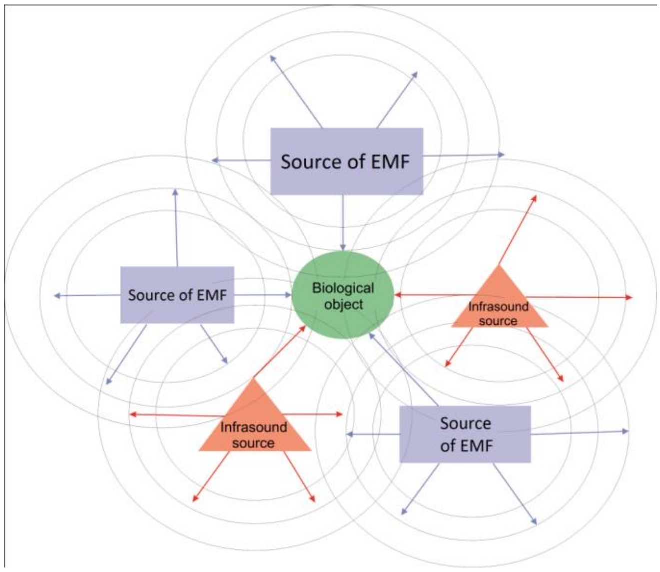

Fig. 1. The scheme of the simultaneous effect of different energy sources of infrasound and electromagnetic fields on a biological object

Having some groundwork in the field of low frequency electromagnetic and infrasound fields study [16], [17], the authors consider it expedient to define the synergetic low-frequency effects in urban areas that will allow identify and analyze the total energy contamination on certain areas and to assess adverse effects of infrasound and low-frequency electromagnetic fields on living organisms.

The existing procedure for monitoring electromagnetic low frequency fields in urban areas requires a separate measurement of the electric field strength (E, V/m) and magnetic field strength (H, A/m). It is believed that the electromagnetic wave in the near zone of the radiation source has not generated yet, so currently during the monitoring of low frequency electromagnetic fields EMF energy parameters are not measured. Normalization by energy indicators takes place only for EMF radio frequency spectrum (in this case the energy exposure and energy flux density are normalized). At the same time there are certain techniques [18] to determine the energy noise parameters in the source near area.

Given the similarity of wave processes occurring in the sound and electromagnetic fields, the authors offer a innovative way to the monitoring of infrasound and low-frequency electromagnetic fields in built up areas – the transition from measuring the amplitude characteristics to determining energy parameters.

Energy parameters for infrasound and low-frequency EMF are complex intensity and its components: active intensity and reactive intensity. Reactive intensity characterizes the process of periodic energy exchange between the power source and the near area. The energy is taken from the source and accumulates in the field, then it is given back to the source. Active intensity characterizes the process of energy radiation.

Generally, the vector of complex intensity is $\vec{I}_k$ equal to:

$$\vec{I}_k = \vec{I}_a + i\vec{I}_i, \quad (1)$$

where

I_a – the vector of active intensity, $\frac{V}{m^2}$;

I_i – the vector of reactive intensity, $\frac{V}{m^2}$.

Determination of the activity intensity will allow us to find the direction to the source of radiation.

In most cases, both in the urban environment and on the territory of industrial enterprises we have to deal with multiple sources of infrasound or EMF, at the same time not all sources are obvious. In this case, the active intensity intensity will indicate the radiation source, which contributes to the pollution in this point the most, and thus helps to develop the most effective methods of protection.

The complex intensity can be determined by using the function of cross-spectrum, where the amplitude of the cross spectrum is equal to the product of amplitudes of both instantaneous spectra and its phase angle is equal to the difference between the phase angles inherent to these cross spectra.

The cross spectrum is a complex value (it has both real and imaginary components). The amplitude of the cross spectrum characterizes the total energy of EMF at a given point, and the phase is the phase difference between the electric and magnetic field strength.

Thus, the complex EMF intensity is equal to:

$$I_k = E \cdot H^* = (|E| \cdot cos\varphi_1 + i|E| \cdot \sin\varphi_1) \cdot (|H| \cdot \cos\varphi_2 - i|H| \cdot \sin\varphi_2 = \\ = |E \cdot |H| \cdot (\cos(\varphi_1 - \varphi_2) + i \cdot |E| \cdot |H| \cdot \sin(\varphi_1 - \varphi_2),| \quad (2)$$

where

E – electric field strength, V/m;

H – magnetic field strength, A/m;

H* – complex conjugate value of the magnetic field strength, A/m;

φ_1 – strength phase of the electric field;

φ_2 – strength phase of the magnetic field.

In equation (2) there are both real and imaginary parts of the electromagnetic field intensity. The real part of the cross spectrum is called "matching (incident) spectrum" or "co-spectrum", and its imaginary part is labelled as "shifted (quadrature) spectrum" or "quad-spectrum" [6].

During time averaging (over a period) the reactive intensity becomes zero, and only the active intensity can be measured.

To determine the reactive intensity 90° is added to the initial phase of the electric field strength and at the output of the spectrum analyser its value is obtained:

$$\mathrm{Re}[I_{\varphi_e+90^\circ}] = \mathrm{Re}[(I_a + i \cdot I_i)e^{-i\pi/2}] = \mathrm{Re}[-i \cdot I_a + I_i] = I_i \quad (3)$$

where

I_a – EMF active intensity, $\frac{V}{m^2}$;

I_i – EMF reactive intensity, $\frac{V}{m^2}$;

φ_E – initial phase of the electric field strength, grad.

Thus, at any point of the low-frequency EMF it is possible to determine the complex intensity – the energy parameter of EMF.

To determine the total energy negative impact on the environment and biological objects first define the active and reactive intensity of the infrasound and electromagnetic field:

$$I_{a_u} = \sqrt{I_{a_u x}{}^2 + I_{a_u y}{}^2 + I_{a_u z}{}^2}; \quad (4)$$

where

I_{a_u} – active intensity of the infrasound field, $\frac{V}{m^2}$;

$I_{a_u x}$ – active intensity of the infrasound field in the projection on the X axis, $\frac{V}{m^2}$;

$I_{a_u y}$ – active intensity of the infrasound field in the projection on the Y axis, $\frac{V}{m^2}$;

$I_{a_u z}$ – active intensity of the infrasound field in the projection on the Z axis, $\frac{V}{m^2}$.

$$I_{i_u} = \sqrt{I_{i_u x}{}^2 + I_{i_u y}{}^2 + I_{i_u z}{}^2}; \quad (5)$$

where

I_{i_u} – reactive intensity of the infrasound field, $\frac{V}{m^2}$;

$I_{i_u x}$ – reactive intensity of the infrasound field in the projection on the X axis, $\frac{V}{m^2}$;

$I_{i_u y}$ – reactive intensity of the infrasound field in the projection on the Y axis, $\frac{V}{m^2}$;

$I_{i_u z}$ – reactive intensity of the infrasound field in the projection on the Z axis, $\frac{V}{m^2}$.

$$I_{a_e} = \sqrt{I_{a_e x}{}^2 + I_{a_e y}{}^2 + I_{a_e z}{}^2}; \quad (6)$$

where

I_{a_e} – active intensity of the electromagnetic field, $\frac{V}{m^2}$;

$I_{a_e x}$ – active intensity of the electromagnetic field in the projection on the X axis, $\frac{V}{m^2}$;

$I_{a_e y}$ – active intensity of the electromagnetic field in the projection on the Y axis, $\frac{V}{m^2}$;

$I_{a_e z}$ – active intensity of the electromagnetic field in the projection on the Z axis, $\frac{V}{m^2}$.

$$I_{i_e} = \sqrt{I_{i_e x}{}^2 + I_{i_e y}{}^2 + I_{i_e z}{}^2}; \quad (7)$$

where

I_{i_e} – reactive intensity of the electromagnetic field, $\frac{V}{m^2}$;

$I_{i_e x}$ – reactive intensity of the electromagnetic field in the projection on the X axis, $\frac{V}{m^2}$;

$I_{i_e y}$ – reactive intensity of the electromagnetic field in the projection on the Y axis, $\frac{V}{m^2}$;

$I_{i_e z}$ – reactive intensity of the electromagnetic field in the projection on the Z axis, $\frac{V}{m^2}$.

Then we define the complex intensities of the infrasound and electromagnetic fields:

$$I_{\kappa_u} = \sqrt{I_{a_u}{}^2 + I_{i_u}{}^2}; \quad (8)$$

where

I_{κ_u} – complex intensity of the infrasound field, $\frac{V}{m^2}$.

$$I_{\kappa_e} = \sqrt{I_{a_e}{}^2 + I_{i_e}{}^2}; \quad (9)$$

where

$I_{\kappa_э}$ – complex intensity of the electromagnetic field, $\frac{V}{m^2}$;

The infrasound and electromagnetic field affects the biological object:

$I_{\kappa_u} \to V_u$;

$I_{ke} \to V_e$;

where

V_u – negative impact on the biological object, caused by infrasound field;

V_e – negative impact on the biological object, caused by electromagnetic field.

Currently, the impact of electromagnetic and infrasound fields is normalized separately, the mutual influence on the living organism is not considered. The total energy impact is subject to the additive function. At the same time, the synergistic (integral) indicator of the energy low-frequency negative is defined by the following expression:

$$V_{\text{int}} = \kappa_1 \cdot V_u + \kappa_2 \cdot V_e; \quad (10)$$

where

κ_1 – weighting factor of the negative impact on the infrasound field on the biological object;

κ_2 – weighting factor of the negative impact on the electromagnetic fields on the biological object.

However, given the data presented in the works of [14], [15], the synergistic indicator of the energy low-frequency negative impact should be determined taking into account the mutual influence of infrasound and electromagnetic fields:

$$V_{\text{int}} = V_u + V_e + f(V_u V_e); \quad (11)$$

where $f(V_u V_e)$ – function that takes into account the mutual influence of the effects of infrasound and low-frequency electromagnetic fields on the biological object;

$$\sqrt{I_{\kappa_u}{}^2 + I_{\kappa_e}{}^2 + f(I_{\kappa_u} I_{\kappa_e})} \to V_{\text{int}}; \quad (12)$$

where $f(I_{\kappa_u} I_{\kappa_e})$ – function that takes into account the mutual influence of the infrasound and low-frequency electromagnetic fields on the biological object.

The algorithm for determining the integral indicator of the energy low-frequency negative impact is shown in Figure 2, where V_x, V_y, V_z – vibrational velocity in the projections on the axes X, Y, Z; P_x, P_y, P_z – sound pressure in the projections on the axes X, Y, Z; E_x, E_y, E_z – electric field strength in projections on the axes X, Y, Z; H_x, H_y, H_z – electric field strength in projections on the the axes X, Y, Z.

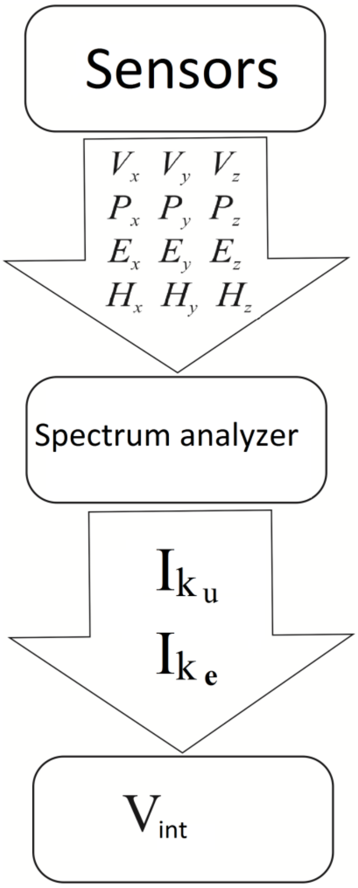

Fig. 2. Algorithm for determining the integral indicator of the low-frequency energy negative impact

Results

Ecological monitoring of the energy impact includes the development of measures aimed at reducing the levels of infrasound and electromagnetic fields.

Measures to protect against physical pollution suggest a decrease in their intensity to the levels that do not exceed the maximum allowable ones. The protection is provided with the choice of specific methods and means with regard to their economic performance, simplicity and reliability of operation.

The organizing process of this protection includes:

– assessment of the levels and their comparison with the regulations;
– selection of appropriate measures and means of protection to ensure the degree of protection under specified conditions;
– organization of the control system for operating protection.

Appearance of hybrid and electric vehicles on the streets, improvement of silencing characteristics of road surfaces and tires will undoubtedly lead to a significant reduction of noise in the audio range. However, the authors believe that the level of infrasound and low frequency noise will remain unchanged due to the generation nature of these oscillations – disruption of air flows from the windswept surface of the vehicle.

The conducted researches have shown that the noise in this frequency range for residential areas exceeds the allowable noise level.

For the estimate of the external infrasound level we chose several different types of vehicles (bus, truck, vans, passenger car, hybrid cars and subcompact city car). The value of infrasonic pressure was estimated using the formula:

$$P = \frac{\rho}{c^3}\left(C_x \cdot S_h\right)^2 \cdot V^6 \cdot l^2, \qquad (13)$$

where

ρ – air density, ρ =1.29 kg/m^3;
c – speed of sound, c=340 m/s;
C_x – drag coefficient of the vehicle;
S_h – Strouhal number;
V – vehicle speed, m/s;
l – length of the vehicle, m.

These studies revealed that increasing the vehicle length by 2 times leads to 10dB increase in the external infrasound level, while increasing the vehicle length up to 12 m increases the external infrasound level by 22 dB.

The conducted research have shown that the infrasound level exceeds the permissible level for residential development, we established the theoretical dependence of the level of this noise type on the composition (structure) of vehicular traffic, vehicle speeds.

Building structures are not only reflective surfaces which may influence the formation of the near field of noise and infrasound waves, but can be used for installation of the system of low frequency noise single absorbers.

For example, the resonant acoustic energy absorber, consisting of an air cavity and a movable element, which own frequencies are tuned to the frequencies with a maximum level in the urban environment noise (Fig. 3).

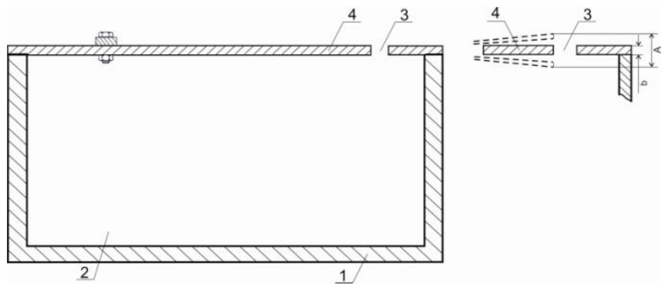

Fig. 3. Resonance absorber. 1 – shell with an air cavity; 2 – air volume; 3 – gap; 4 – movable element

Currently it is common to assess the ecological safety of the car mostly by the noise level, by the content of harmful substances in exhaust gases and the impact of these emissions on the atmosphere. However, according to the published data, the share of electromagnetic pollution by vehicles in urbanized areas is 18-32% [19], and the problem of electromagnetic pollution in urban areas is quite urgent [20]. We believe that the increase in the total number of vehicles (especially electric and hybrid) on city highways will increase the level of the electromagnetic field. The authors conducted the study of the electromagnetic field characteristics along a city road, depending on traffic intensity, distance from the roadway, frequency range. Some results are shown in Table 1.

TABLE 1. Results of the study of electromagnetic fields along the road

Traffic intensity	Electromagnetic field characteristics in the frequency range of 5 Hz – 2 kHz		Electromagnetic field characteristics in the frequency range of 2 kHz – 400 kHz		Electromagnetic field characteristics at frequency of 50 Hz	
	E, V/m	B, mcT	E, V/m	B, nT	E, V/m	H, A/m
0 vehicle/min	2	0.01	0.01	0	0.7	1.4
35 vehicle/min	6	0.1	0.3	1	2	2.1
58 vehicle/min	15	0.2	0.8	1	6	2.97

The obtained results confirm that together with the increase in traffic intensity on the road, indicators of strength of electric and magnetic fields in different frequency ranges of measurement increase.
Due to the similarity of wave processes, constructions are reflective surfaces as well, they influence the formation of the near-field low-frequency electromagnetic field. In construction of structures it is necessary to use known regularities to improve the effectiveness of electromagnetic field shielding, for example, at low frequencies the electrical shielding effectiveness is practically determined by the quality of earthing, and at high frequencies the shielding efficiency, operating in an electromagnetic mode, is determined by its thickness, conductivity and magnetic permeability along with the quality of earthing.
We believe that conductive paints, which are manufactured by introducing conductive materials into their content, should be used more widely for painting facades, fences and other barriers in order to reduce the level of electromagnetic field. There are the following conductive materials: colloidal silver, graphite, carbon black, metal oxides, powdered aluminium, copper and others.
The paint with acetylene black and graphite used as a conductive pigment gives the best results. Conductive paints provide the shielding effectiveness of not less than 30 dB in a wide frequency range.
To implement the theoretical provisions, the authors measured the energy parameters of infrasound and low frequency EMF.
In the anechoic chamber (closed volume) based on measurements of air particle oscillatory velocity and sound pressure they determined the spatial distribution of active and reactive intensity from the infrasound source at a frequency of 6 Hz. The level of active and reactive intensity reached up to 50 dB.

To determine the intensity of the low-frequency active EMC we created the measuring system, which includes measuring antennas, oktafon, analogue-to-digital converter (ADC) and a dual spectrum analyser. Near the power cable we simultaneously measured the electric and magnetic fields strength, then signal converted by the ADC was transmitted to the spectrum analyser and the activity intensity was determined, the spectrum of this intensity is shown in Figure 4.

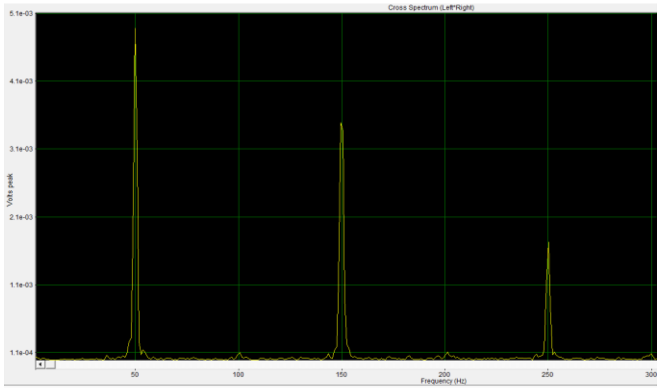

Fig. 4. Active intensity spectrum of low frequency electromagnetic field

Discussion
The authors believe that there should be a transition to a new paradigm in the implementation and evaluation of ecological monitoring data based on the principles of complexity and ratemeter use in determining the impact of physical factors, as well as the principles of in vitro environmental safety testing for multi organ chip with microcirculation imitation. This will allows us to move from stating alarming rate of growth of eco-related diseases, including among children, to identifying areas of high ecological danger of the urban environment and the most important factors of negative impact. Which in turn makes the most efficient means to focus on the development and implementation of measures for the suppression of the most important factors and normalization of habitat.
With simultaneous exposure to infrasound and low-frequency electromagnetic fields it is necessary to conduct sanitary-epidemiological studies, taking into account their mutual effect on living organisms and develop new standards regulating the impact of these factors on humans, working environment and residential areas.
Benefits of in vitro environmental safety testing primarily consist in increasing the speed of testing, avoiding animal testing because they are not necessarily a relevant model for human safety assessment, as some of the processes proceed very differently in animals, avoiding the testing on monocultures as the system component for assessing the cumulative impact of all negative factors on human cells is added [21]. Bio Chip technologies are the most promising for conducting such studies. Micro bioreactors in which cell miniature models of various organs and tissues of the human body function, allow us to assess the impact of various factors on the reduced model and to obtain information about their impact on the real human body [22]. Micro bioreactor

"Homunculus", created in the RDC "BioKlinikum", is shown in Figure 5.

Fig. 5. Micro bioreactor "Homunculus"

Suggested innovative technologies of implementation and evaluation of the monitoring results allow us to detect urban areas with high environmental risk, taking into account the complex effects of negative factors on the health of population, as well as to develop the most effective methods of protection.

Determination of the synergistic energy low-frequency impact in the urban environment allows us to estimate the negative impact of electromagnetic and infrasound fields on biological objects objectively, as well as to develop effective measures to improve environmental safety of urban areas.

Conclusion

1. This paper proposes innovative way to the monitoring of low-frequency energy pollution.
2. The authors proved the possibility of determination of the energy technogenic impact of infrasound and low-frequency electromagnetic fields, taking into account the mutual influence of these factors on living organisms
3. We suggested the algorithm for determining the integrated indicator of the low-frequency energy impact by measuring complex intensities of infrasound and low-frequency electromagnetic fields.
4. We substantiated the necessity of carrying out sanitary-epidemiological studies and development of a new legal framework regulating the effects of infrasound and low-frequency electromagnetic fields, taking into account their reciprocal influence on living organisms and the environment.
5. It is shown that building structures, as a component of urban environment, currently are insufficiently utilized in order to reduce the negative influence of physical factors. Measures proposed by the authors can reduce the levels of electromagnetic fields and noise in dense urban areas. It is expedient to further research the protective properties of building structures.

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