Розглянуто багатофункціональні перегородки та їх вплив на рівні шуму. Звернуто увагу на те, що існуючи системи класифікації будівельних перегородок розглядають їх, виходячи із зручності їх використання, матеріалу, дизайну тощо. При цьому недостатньо приділяють уваги їх впливу на показники зменшення рівня шуму у офісних приміщеннях.

Перегородки виготовляють з різних матеріалів, які мають різні властивості, є різними за формою, на різній відстані від полу перекривають приміщення або робочий простір. У таких випадках виникає складна задача вибору певних типів перегородок, які, як це показано у роботі, дозволяють вирішити завдання оптимізації умов праці та зменшити негативний вплив шуму на здоров'я працівників. Виконані дослідження довели, що поставлена задача зменшення шуму завдяки використання перегородок досягається. Фактори, які особливо потрібно врахувати: висота перегородки (ступень перекриття перегородкою відстані до стелі), матеріал перегородок, наявність технологічних отворів та геометрію їх розташування. Виявлено, що двошарові перегородки, які виконано з важких матеріалів (густина ≈2500 кг/м^3) та перекривають на 100 % приміщення за висотою, здатні зменшувати рівень шуму в 2–3 рази (із 90 дБА до 30–45 дБА). Перегородки із скла (труби скляні), середньої ваги (густина ≈1200 кг/м^3), зменшують шум в 1,5–1,6 раз. Якщо перекриття приміщення не повне або є отвори, вентиляційні шахти тощо, то ефект впливу перегородок значно зменшується, зводячи його практично нанівець. Відчутний вплив перегородок відбувається у частотному діапазоні 200–3000 Гц при рівнях шуму 40–60 дБА.

Шум досліджувався у приміщеннях типу «Open space», де були застосовані різні варіанти перегородок (скляні труби у металевому каркасі, керамічні плити, пінопластові плити). У результаті досліджень було встановлено, що перегородки можуть суттєво впливати на показники шуму, але тільки за умов повного перекриття приміщення по висоті, зачинених дверях і будівельних каналів у стінах. Встановлено, що матеріал перегородок не впливає на показники шуму, якщо ступінь перекриття не повна (менш 100 %).

Дослідження довели перспективність наукового обґрунтування застосування перегородок та визначення зв'язку перекриття приміщення із факторами, які впливають на працівників задля поліпшення умов праці, яке в свою чергу дозволить зменшити профзахворюваність, мінімізувати плинність кадрів, підвищити ефективність праці

Ключові слова: офіс типу «Open space», локалізація робочого простору, шум, будівельні перегородки

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DETERMINING THE EFFECT OF MULTIFUNCTIONAL PARTITIONS ON NOISE LEVEL AT "OPEN SPACE" OFFICES

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1. Introduction

Human health is significantly affected by noise whose magnitude exceeds 70–80 dBA, that is, those can be actually heard even without special devices (the noise in the underground when a train arrives at the station is ≥80 dBA). However, a person is always surrounded by background noises, such as noises that accompany the work of a person at "Open space" offices. These noises are at the level of ≤70 dBA, but there is their negative impact that accompanies the work of an employee for many years. It is very difficult to track the consequences of such effects in time, because these noises have the characteristic of the "white noise" and, as a rule, are neglected by managers and employees. The organism of an employee becomes adapted to such noises, but this does not mean that they disappear, they exist and they gradually destroy human health [1].

According to the data of the European Environment Agency, environmental noise annually causes at least 10,000 cases of premature death in Europe. Nearly 20 million of adults suffer from irritation and another 8 million suffer from sleep disorders as a result of environmental noise. The World Health Organization recognized noise as the second most significant environmental cause of poor health. Air pollution was identified as the first cause. 7 EAP (EU, 2013) sets a goal to significantly reduce noise pollution before 2020. The Regional Office of WHO for Europe developed a series of guidelines that are based on growing awareness of the consequences of the influence of environmental noise on health [2].

Noise is one of the most common complaints of employees working in corporative office premises, especially in the concepts of open space office, where employees are gathered in the large space where there is no separation. Multiple studies showed that too much noise in an office can seriously reduce performance and increase stress, not to mention less satisfaction with work and morale of employees. Research at the University of Sydney in 2013 revealed that the lack of privacy is the biggest frustration for employees [3].

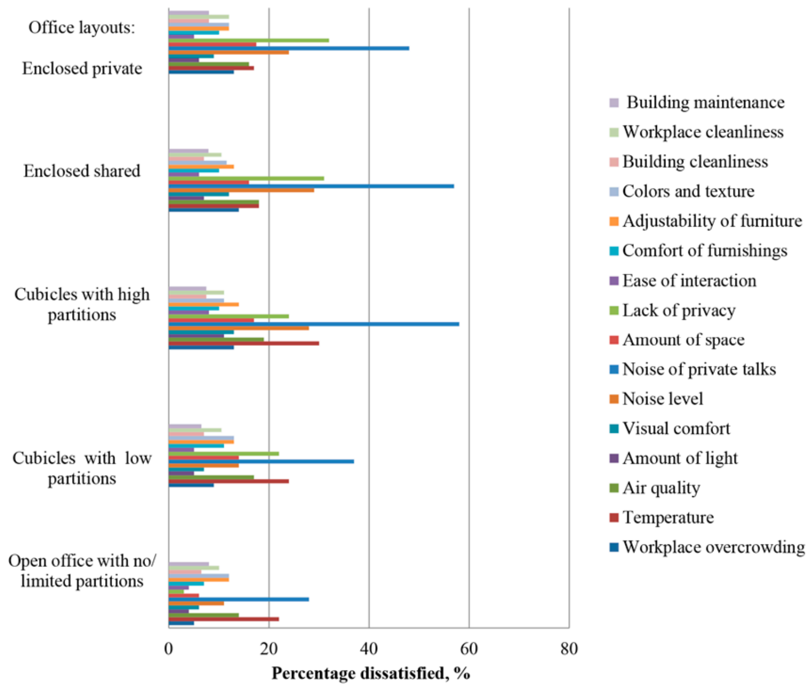

Fig. 1. Illustration to the research by Sidney University [4]

Most managers and office staff report a nearly constant noise in the workplace. Many people do not have enough quiet space to meet and concentrate, says a new report from Oxford Economics, commissioned by Plantronics company. 75 percent of workers say that they need to take a walk outside, and 32 percent use headphones to distract attention. Employees in the noisiest offices are most likely to say that may leave their job within the next six months [4].

Effects of continuous noise pollution, in addition to hearing damage, can cause other health problems: headache, high blood pressure, fatigue, irritability, digestive disorders, increased susceptibility to colds and other minor infections.

It is possible to achieve a decrease the noise effect in the workplace in different ways: to change equipment or to use it in a soundproof room; to change the place of work; to change the work schedule; to use individual means of protection from noise [5].

Paper [6] presents the classification of partitions of the "Open space" office. It is indicated that partitions must be environmentally safe, comfortable and flexible to apply. The most popular materials used for manufacturing of partitions are the following: polyurethane foam, polystyrene, wood, aerated concrete, and keramzite panels. Based on this, all partitions can be divided according to acoustic resistance of sound, which is directly proportional to the partition weight and sound frequency, into three types: heavy-weight, for example, ceramic and brick; medium-weight, such as glass and those made of wood; light-weight, for example, foam plastic, plywood, etc. In addition, according to the degree of enclosure of the room by height, it is possible to distinguish between the partitions with complete enclosure (100 %), with incomplete enclosure (from 75 % up to 99 %), and semi-enclosure (from 50 % to 74 %).

Noise was studied in "Open space" offices, where different variants of partitions were applied (glass pipes in the metal casing, ceramic panels, and polystyrene). The purpose of the study was to establish the possibility of reduction of the noise level due to the use of multifunction partitions. It was established that partitions can reduce noise, but only under conditions of complete enclosure of premises by height and closed doors and construction channels in the walls. In this case, the material, from which partitions are made, influences the indicators, but not significantly.

Surrounding noise is becoming a growing problem of public health care. The noise of the environment causes sleep disorders [7, 8], learning disorders, hypertension, coronary heart disease [9], and irritability [10].

In 2018, the updated Guidelines by WHO on the issue of noise in the environment for Europe [11] was released and presented compelling evidence that noise is one of the dominating environmental threats of physical and mental health and well-being of the population.

The authors of Guidelines [12] note that in assessing the burden of diseases, environmental noise is second after air pollution among the risk factors associated with the environment. By this time, we have gained enough information for quantitative estimation of the burden of disease caused by environmental noise for such effects as cardiovascular disease, cognitive disorders, sleep disorders, tinnitus and irritability. The evidence of the positive impact of noise reduction on health and various measures to reduce the noise level are also considered in the Guidelines of WHO. They deal with "environmental" noises, such as the noise of wind turbines, noise during leisure, transportation noise (aviation, highways and railroads), but do not deal with noise during work. Although some of the recommendations can be applied to noise in the workplace.

The noise levels influence a human most of all during activities, particularly in the workplace. This unfavorable operating factor, in addition to the above deviations for health, may cause the deterioration of efficiency, attention span, concentration, reduce job satisfaction, and weaken the motivation to work. The noise levels that are excessive relative to the accepted can cause hearing diseases, professional and permanent loss of hearing [13]. Even at those workplaces (for example, in offices), where the noise level usually does not exceed the norms established in Ukraine [14] or in other countries, workers and researchers of this problem identify the negative impact of noise on health and work productivity [15, 16].

2. Literature review and problem statement

In paper [17], which explores one of the common types of offices – "Open space" offices, the advantages and disadvantages of such offices were considered. It was noted that noise is one of the major disadvantages of such offices, but the article did not indicate the relation of the noise levels with different types of partitions and other methods of reducing the noise level in the workplace.

In paper [18], authors describe in detail the shortcomings of office work, note high psycho-emotional tension, lack of motion during work, dissatisfaction of workers with labor intensity that is worsened even more by adverse conditions of a microclimate, light, noise, etc. It was noted that many offices have partitions made of materials that are ineffective for sound absorption. The authors underline that adverse working conditions, including noise, have an impact on the state of health of office workers and that the studies of this problem, as well as scientific substantiation, development and implementation of measures to improve working conditions, will be relevant.

There is enough research into noise propagation, its impact on a human, ways to reduce the noise level near highways [10, 19, 20], airports [21–23], the wind farms [24], but there is not much research which focuses on noise propagation and the means of its reduction. Research [25] links different levels (39 dBA and 51 dBA) of office noise with good health and concentration of employees. Greater fatigue, reduced attention span were observed in the case where the noise level was higher (51 dBA).

Article [26] considered the use of headphones with disguising noise, and although this method made it possible to increase concentration in some cases, but was recognized to be ineffective.

In papers [27, 28], authors studied the noise level in office premises, but did not propose the ways to solve the problem. The authors of [29] explored the acoustic properties of the “Open space” office and made conclusions that it is necessary to use partitions and sound absorbing ceiling in order to increase acoustic comfort.

The performed analysis makes it possible to reveal the insufficient level of scientific studies that focus on identifying the problems of protection of employees of the OS offices on acoustic loads during the working day. It has to do with the fact that partitions in such areas, as a rule, are not designed by construction specialists, but rather by owners of premises themselves according to the recommendations of sellers of enclosures. The result of such implementations is the low effect of the installed partitions. When designing partitions, it is necessary to take into consideration the guidance on calculation and design of soundproofing of enclosures for residential and public buildings (DSTU-N B V.1.1-34:2013) [30]. The main aim of the performed studies was to detect already installed partitions that meet the requirements of DSTU regarding the noise in office premises.

3. The aim and objectives of the study

The aim of this study was to establish the dependence of a noise level at “Open Space” offices (“OS”) on the material and the degree of enclosure of premises in height by partitions. This will enable determining the compliance of the functional working areas, created by partitions, with production goals.

To achieve the aim, the following tasks were set:

– to divide partitions according to requirements for noise reductions in working areas according to work tasks that should be performed;

– to make an analysis of the possibility of reducing noise in premises, localizing premises or working areas with the noise source using partitions;

– to assess noise propagation at different state of the openings in partitions (doors, vents) in the premises at its 100 % enclosure in height and less;

– to make a comparative analysis of noise propagation in premises with and without partitions.

4. Materials and methods to study the influence of installed partitions on noise in working areas of premises

4. 1. Instruments and equipment used in the study of noise

Measurement of noise in octane bands or noise level was conducted using noise meter NVM003 – noise and vibration meter that corresponds to the current requirements of the State standard of Ukraine (Fig. 2).

Fig. 2. Noise and vibration meter NVM003 (“Vibropribor” company)

Noise standards in workplaces are regulated by the DSN 3.3.6.037-99 “Sanitary norms of industrial noise, ultrasound and infrasound” [14] and the American electronic reference book “Assessment of the impact on health – UCLA (UCLA-HIA) [31]. Parameters of constant noise in workplaces, that are regulated, are the levels of sound pressure in octave bands with geometric mean frequencies 31.5; 63; 125; 500; 1,000; 2,000; 4,000; 8,000 Hz in decibels. It is allowed to accept noise level in dBA as the characteristic of constant noise for reference hygienic assessment of the parameters of permanent wide-band noise in the workplace. Adjustment involves the introduction of amendments to sound pressure levels, depending on frequency. An adjusted level of sound pressure is equal to:

$$L_A = L - \Delta L_A, \qquad (1)$$

where L is the value of overall noise level; ΔL_A is the adjusted, dB.

Adjustment is necessary to approximate results of objective measurements to subjective perception of noise by a human. Standard values of adjustment are shown in Table 1.

Table 1

Standard values of adjustment

Frequency, Hz	16	31.5	63	125	250	500	1,000	2,000	4,000	8,000
ΔL, dB	80	42	26.3	16.1	8.6	3.2	0	–1.2	–1.0	–1.1

In Table 1, frequency ranges (250–2,000 Hz), which are most typical in "OS" office (as proved by executed research), are highlighted in grey color.

4. 2. Procedure for measurement of noise parameters

Procedure for measuring sound levels with noise meters and the calculation of the equivalent level was established according to regulation DSN 3.3.6.037-99.

During the measurements, the microphone was placed at the height of 1.5 m above the level of the floor or of the workstation. The microphone was orientated in the direction of the maximum noise level and remote not less than by 0.5 m from the operator, conducting the measurements. During the measurement of octave levels of sound pressure, the switch of frequency characteristic of the device was set into the "filter" position. Octave levels of sound pressure were measured in the bands of geometric mean frequencies of 31.5–8,000 Hz.

When conducting measurements of sound levels, the dBA switch of frequency characteristic of the device was set in "A" position (using appropriate filters, where the sensitivity at low and high frequencies was decreased).

The layout of the "OS" with the grid of noise measurement points and according to the values of partitions is shown in Fig. 3. The distance between the lines was 3.5 m, which is equal to the frequency of 1,155≈1,200 Hz that in research corresponds to the frequency of the sound (noise) source.

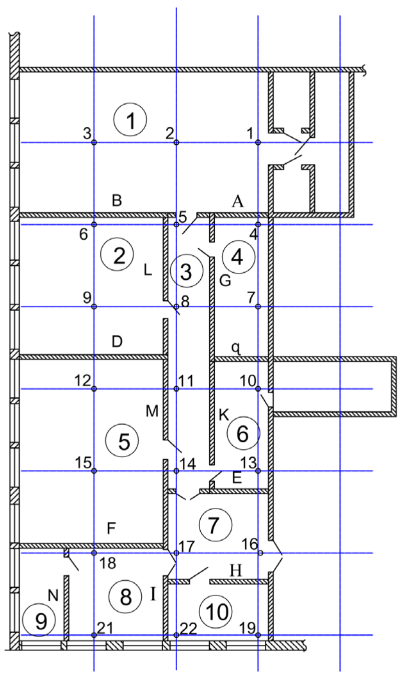

Fig. 3. Layout of "Open Space" office with a grid of measurement points with designation of partitions (Table 2) and separated research areas

The source of noise is an electric bell, which is mounted on a wooden panel with a switch and an electric wire of connection to the electric network (Fig. 4).

In the study, we measured the equivalent noise levels that have fluctuations in time. That is why to determine the equivalent (for energy) noise level, the switch of time characteristics of the device was in the "slow" position. The value of the noise levels was accepted by the indicators of the pointer of the device at the moment of counting.

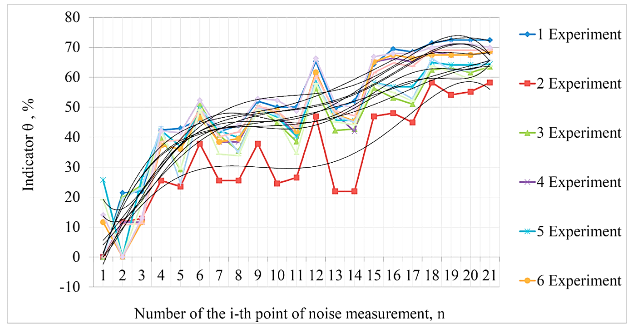

Fig. 4. Physical appearance and noise source circuit

During the measurement of maximum levels of pulse noise, the switch of the time characteristic of the device was set to the "pulse" position. The values of the levels were accepted by the maximum indicator of the device.

Noise was measured in areas formed by the partitions according to Fig. 3. Characteristics of the partitions are shown in Table 2.

Table 2

Conditional designation and description of partitions in the "OS" premises

Designation of the circuit	Description of partition	
A	Combined: 2 layers of ceramic panels (87.5 % degree of enclosure (d.e.)), organic glass (13 % d.e.)	Combined partition up to the ceiling: ceramic panel of 3.15 m in height, organic glass of 0.35 m in height (placed above)
B	2 layers of ceramic panels (100 % d.e.)	Ceramic panel up to the ceiling
C	2 layers of ceramic panels (87.5 % d.e.)	Ceramic panel of 3.15 m in height. Overall height of ceiling is 3.60 m
D	2 layers of ceramic panels (100 % d.e.)	Ceramic panel up to the ceiling
E	2 layers of ceramic panels (100 % d.e.)	Ceramic panel up to the ceiling
F	Glass pipes C (100 % d.e.)	Glass pipes with rubber compactor up to the ceiling
G	Glass pipes (60 % d.e.)	Glass pipes with rubber compactor of 2.10 m in height. Overall height of the wall is 3.60 m
H	Glass pipes (100 % d.e.)	Glass pipes with rubber compactor up to the ceiling
I	Combined: 2 layers of ceramic panels (86 % d.e.), organic glass (14 % d.e.)	Combined partition up to the ceiling: ceramic panel of the height of 3.10 m, organic glass of the height of 0.50 m (located above)
K	Glass pipes (60 % d.e.)	Glass pipes with rubber compactor of the height of 2.10 m
L	Combined: 2 layers of ceramic panels (88 % d.e.). Foam plastic panels with two layers of paper (12 % d.e.)	Combined partition up to the ceiling: 2 layers of ceramic panels of the height of 3.15 m; foam plastic panels of 0.45 m in height covered by paper on two sides, located above the ceramic panels
M	Combined: 2 layers of ceramic panels (88 % d.e.), Foam plastic panels with two layers of paper (12 % d.e.)	Combined partition up to the ceiling: 2 layers of ceramic panels of the height of 3.15 m; foam plastic panels of 0.45 m in height covered by paper on two sides, located above the ceramic panels
N	Glass pipes (100 % d.e.)	Glass pipes with rubber compactor up to the ceiling

Duration of measurement of non-permanent noise:

– for noise that varies in time, measurements consisted of three cycles of 10 minutes each;

– for pulse noise, measurement duration was 30 minutes. The data on experiment planning are shown in Table 3.

Table 3

Planning experiments on studying noise in "OS" premises

Number of experiment	Door apertures in partitions	Ventilation	Number of the noise source point in zone 1
1	closed	opened	1
2	opened	opened	1
3	opened	Half-closed	1
4	closed	Half-closed	1
5	opened	Half-closed	2
6	closed	Half-closed	2
7	opened	closed	1
8	closed	closed	1
9	opened	closed	2
10	closed	closed	2

Based on the experiment plan, the noise source location, existence of technological openings in the partitions, material of partitions and degree of working space enclosure by a partition varied.

5. Results of studies of noise in "Open space" premises in the experiments

Studies of noise in "OS" premises in the zones separated by partitions (experiment 1).

The noise source (electric bell) was located at point 1 (Fig. 4). All the doors in the partitions were *closed*, ventilation was *opened* (Table 3). Tables 4 and 5 show the noise levels in measurement points.

The noise was studied along the frontal location of the partitions relative to the noise source.

Degree of enclosure (φ, %) of premises (Table 4) by the partition along the height was calculated from the formula

$$\varphi=100\cdot h_1/h_2, \quad (2)$$

where h_1 is the height of premises, m; h_2 is the height of the partition, m; 100 – percentage, %.

The difference of noise (Δ, dBA) according to measurement points (Fig. 2), $\Delta=L_1-L_i$, where L_1 is the noise level at point 1 (noise level), L_i is the noise level in the measurement point.

The noise attenuation factor was determined from formula:

$$\beta=\Delta/L_1, \quad (3)$$

where L_1 is the noise level at point level 1 (noise source).

In percentage, coefficient β, accepts the form of indicator θ (%) from the following expression

$$\theta=\Delta\cdot 100/L_1. \quad (4)$$

In experiment 2, all the doors in the partitions were *opened*, ventilation was *opened* (Table 3). Background noise in measurement points 1–3 was equal to 37 dBA, at points 4 and 5 – 32 dBA, in all the other 30–31 dBA.

In experiment 3, all the doors in the partitions were *opened*, ventilation was *half-opened*. Background noise in measurement points 1–3 was equal to 31–32 dBA, at points 4 and 5 – 29 dBA, in all the other points it was the same, 28 dBA.

Table 4

Results of study at measurement points in experiment 1

Partitions	Number of the noise measurement point, i	Background noise in measurement point, dBA	Noise level, measured in corresponding point L_i, dBA	Difference of noise level at the noise source at assigned point, Δ_i, dBA	θ, %
–	1	32	98	0	0.0
–	2	35	77	21	21.4
–	3	35	76.5	21.5	21.9
A	4	31	56.5	41.5	42.3
B	5	32	56	42	42.9
B	6	32	53	45	45.9
A	7	32	57	41	41.8
B	8	33	55	43	43.9
B	9	32	47	51	52.0
A+C	10	35	49	49	50.0
B	11	33	49	49	50.0
B+D	12	30	34	64	65.3
A+C	13	33	49.5	48.5	49.5
B	14	32	47	51	52.0
B+D	15	30	35	63	64.3
A+C+E	16	30	30	68	69.4
B+E	17	30	31	67	68.4
B+D+F	18	27	28	70	71.4
A+C+E+H	19	27	27	71	72.4
A+C+E+H	20	27	27	71	72.4
B+D+F	21	27	27	71	72.4

In experiment 4, all the doors in the partitions were *closed*, ventilation was *half-opened*. Background noise in measurement points 1–3 was equal to 31–32 dBA, at points 4 and 5 – 29 dBA, in all the other points it was the same, 28 dBA.

In experiment 7, all the doors in the partitions were *opened*, ventilation was closed (Table 3). Background noise in measurement points was the same, 28 dBA.

In experiment 8, all the doors in the partitions were *closed*, ventilation was closed (Table 3). Background noise in measurement points was the same, 28 dBA.

Table 5

Results of studying noise at point 1

Number of the i-th point of noise level measurement, *n*	θ, %				
	No. of experiment according to Table 3				
	2	3	4	7	8
1	0.0	0.0	0.0	0.0	0.0
2	11.7	19.8	11.6	19.3	10.7
3	12.8	24.0	11.6	23.2	11.2
4	25.5	39.6	37.2	43.5	38.5
5	23.5	29.2	36.0	24.6	39.0
6	37.8	51.0	47.7	49.3	49.2
7	25.5	40.6	38.4	43.5	40.1
8	25.5	35.4	38.4	34.8	41.7
9	37.8	50.0	50.0	49.8	50.3
10	24.5	44.8	47.7	47.3	48.7
11	26.5	38.5	40.7	43.0	43.3
12	46.9	56.3	61.6	58.0	60.4
13	21.9	42.2	47.7	47.3	48.7
14	21.9	42.7	41.9	44.9	47.1
15	46.9	56.3	65.1	58.0	61.5
16	48.0	53.1	66.3	56.5	64.7
17	44.9	51.0	65.1	52.7	63.6
18	58.2	62.5	68.6	66.2	69.0
19	54.1	63.0	67.4	62.3	69.0
20	55.1	61.5	67.4	62.3	69.0
21	58.2	63.5	68.6	65.7	69.0

Table 6 shows the noise levels in measurement points in experiments 5, 6, 9 and 10. Fig. 2 shows the measurement. The noise source was at point 2.

In experiment 5, all the doors in the partitions were opened, ventilation was half-opened. Background noise in the measurement points 1–3 was equal to 31–32 dBA, and at points 4 and 5 – 29 dBA, in all the other points – 28 dBA.

In experiment 6, all the doors in the partitions were closed, ventilation was half-opened. Background noise in the measurement points 1–3 was equal to 31–32 dBA, at points 4 and 5 – 29 dBA, in all the other points it was the same, 28 dBA.

In experiment 9, all the doors in the partitions were opened, ventilation was closed. Background noise in all the measurement points was the same, 28 dBA.

In experiment 10, all the doors in the partitions were closed, ventilation was closed. Background noise in measurement points was the same, 28 dBA.

Table 6

Research results at measurement points

Number of the i-th point of noise level measurement, n	θ, %			
	No. of experiment according to Table 3			
	5	6	9	10
1	25.7	11.6	19.1	14.0
2	0.0	0.0	0.0	0.0
3	26.2	11.6	18.1	13.0
4	42.2	37.2	41.7	42.0
5	36.9	36.0	29.4	41.5
6	49.5	46.5	49.0	52.3
7	42.2	38.4	34.3	42.5
8	39.8	39.5	33.8	44.0
9	49.0	48.8	49.0	52.8
10	46.6	48.8	46.1	52.3
11	40.3	41.9	34.3	48.7
12	58.7	61.6	57.8	66.3
13	45.6	47.7	45.1	51.3
14	45.6	45.3	44.1	49.7
15	58.2	65.1	57.8	66.8
16	56.8	67.4	54.9	67.9
17	56.8	66.3	52.0	67.9
18	64.9	67.4	63.7	69.9
19	64.1	67.4	61.8	71.0
20	64.1	67.4	59.3	71.0
21	64.3	68.6	63.7	69.9

Determining sound conductivity of partitions.

Fig. 5 shows the distribution of noise indicators at "OS" premises.

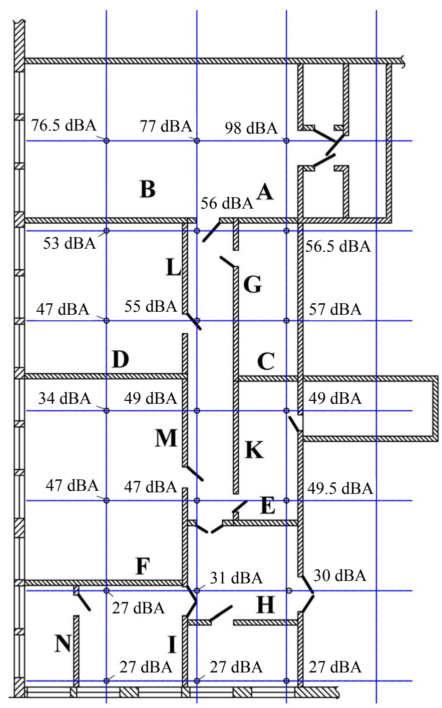

Fig. 5. Distribution of noise indicators by scale A in the "OS" office

Table 7 shows the calculation of coefficient of sound conductivity of partitions $\alpha_к=(L_i-L_j)/L_i$ in the corresponding zones, according to the location of the partitions

Table 7

Calculation of coefficient of sound conductivity of the partitions

Designation of partition (degree of enclosure)	Number of point of noise level measurement, i	Noise level from the noise source, measured in corresponding point L_i, dBA	Number of noise measurement point, j	Noise level from the noise source, measured in corresponding point L_j, dBA	L_i-L_j	α_K
Sound propagates frontally to the partition						
A (75 %)	1	98	4	56.5	41.5	0.42
	2	77	5	56	21	0.27
B (100 %)	3	76.5	6	53	23.5	0.31
D (100 %)	9	47	12	34	13	0.28
C (75 %)	7	57	10	49	8	0.14
E (100 %)	13	49.5	16	30	19.5	0.39
F (100 %), glass	15	35	18	28	7	0.20
H (100 %), glass	16	30	19	27	3	0.10
Sound propagates in parallel to the partition						
L (100 %)	5	56	6	53	3	0.05
	8	55	9	47	8	0.15
G (75 %), glass	4	56.5	5	56	0.5	0.01
	7	57	8	55	2	0.04
K (75 %), glass	10	49.5	11	49	0.5	0.01
	13	49.5	14	47	2.5	0.05
M (100 %)	11	49	12	34	15	0.31
	14	47	15	35	12	0.26
I (100 %)	17	31	18	28	3	0.10
	20	27.5	21	27	0.5	0.01

Table 8 shows the of data of measurements of coefficient α at the distance of 1 meter in front of the partition (source noise L_1) and 1 meter behind the partition, L_2 (made at the same time).

Table 7 shows the value of coefficient of soundproofing of the partitions in two variants of noise propagation. In the first case, the noise acts frontally, that is the noise source is situated in front of the partition. In the second case, noise propagates in space, which has restrictions on the sides, where there are partitions (parallel to the walls). The partitions made of ceramic material have high efficiency and those made of glass have very low efficiency. The experiment has significant errors because of the essential background influences of the frontal sound pressure; therefore, we carried out the experiment with direct study of acoustical properties of noise on the specific partition and presented the results in Table 8. From Table 8, we can conclude that if the influence of noise on the partition is frontal, the most effective partition for noise reduction is a combined partition from two layers of ceramic material, to which, for example, foam rubber panels (α=0.43–0,54) were added.

Fig. 6 shows the dependence of coefficient α on degree of premises enclosure (φ) by different partitions.

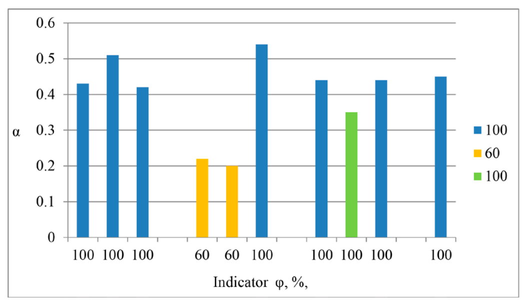

Fig. 6. Dependence of coefficient **α** on degree of premises enclosure (φ, %) by different partitions:
— partitions from ceramic panels (two layers),
— glass partitions (glass pipes, φ=60 %),
— glass partitions (glass pipes, φ=100 %)

Table 8

Results of measurements of coefficient α of each partition directly

Designation of partition	Description of the partition	φ, %	L_1, dBA	L_2, dBA	$\Delta=L_1-L_2$, dBA	α
A	Combined: 2 layers of ceramic panels (87.5 % of degree of enclosure (d.e.)), foam plastic panels (13 % d.e.)	100	98	55,7	42,3	0,43
B	2 layers of ceramic panels (100 % d.e.)	100	98	48,3	49,7	0,51
L	Combined: 2 layers of ceramic panels (88 % d.e.), foam plastic panels with two layers of paper + organic glass insertions (12 % d.e.)	100	98	56,7	41,3	0,42
G	Glass pipes (60 % d. e.)	60	98	76	22	0,22
K	Glass pipes (60 % d. e.)	60	98	78	20	0,20
M	Combined: 2 layers of ceramic panels (88 % d. e.), foam plastic panels with two layers of paper (12 % d. e.)	100	98	44,7	53,3	0,54
F	Glass pipes (100 % d.e.)	100	98	54,8	43,2	0,44
H	Glass pipes (100 % d.e.)	10	98	63,6	34,4	0,35
I	Combined: 2 layers of ceramic panels (86 % d.e.), organic glass (14 % d.e.)	100	98	54,5	43,5	0,44
E	2 layers of ceramic panels (100 % d. e.)	100	98	53,8	44,2	0,45

Propagation of sound waves in 3 directions (Fig. 3) at the distance of 21 m from the noise source through the partitions:

– conventional partition (corridor with open doors);

– through 3 partitions (100 % enclosure);

– through 3 partitions, combined by height (one 100 %, two 75 %).

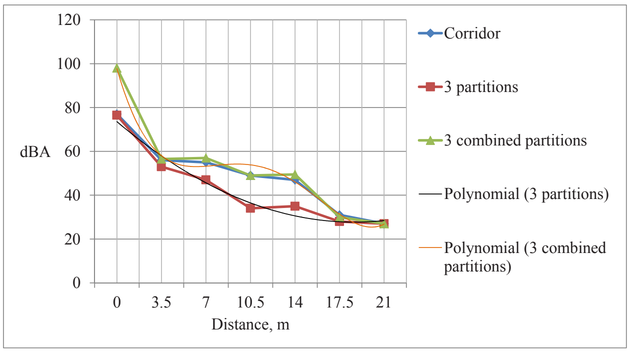

Fig. 7. Dependence of noise propagation in three conventional directions

The derived polynomial dependences are described by the trends with probability R^2=0,96–0,98:

– corridor and 3 combined partitions:

$$y=0.6439x^4-11.331x^3+69.292x^2-177.88x+217; \qquad (5)$$

– 3 partitions:

$$y=1.6131x^2-20.423x+92.357, \qquad (6)$$

where x is the distance to the measurement point from the noise source, m; y is the noise level at the measurement point, dBA.

Analyzing the results obtained, it may be noted that at the distance of 7 and 14 meters, there was an increase in noise, the source of which was opened doors in the partitions that led to the corridor. In the variant with 3 partitions, there was also increased noise in these points, however, insignificant.

Fig. 8 shows a graphical representation of the results of noise measurement in the experiments when the noised source was at point 1.

According to the derived curves, we can conclude that the partitions have the least influence on the noise level in the premises of the "OS" office when the doors and vents are *opened* (experiment 2).

Fig. 10 shows the research results in the form of the curves that with probability R^2 in the range of values from 8.0 (experiment 9) to 9.5 (experiment 1) describe with the curved of the trend the dependences of influence of the partitions in the "OS" office on noise.

The overall dependence of the influence of partitions on noise in the experiments is almost similarly described by polynomials of 5–6 order shown in Table 7. Peak values of coefficient of soundproofing (%), which are reflected in Fig. 3–5, characterize the best level of soundproofing, and vice versa, those that are in the lower points characterize open doors, vents, poor sound proof properties of the partitions. Thus, point 5 is the opening (door) in the partition and it is seen that its position significantly influences the noise propagation in the building, because it is the nearest to the noise source. Points 4, 7, 10 and 13 are located along the vent openings and sound proof effectiveness is lower.

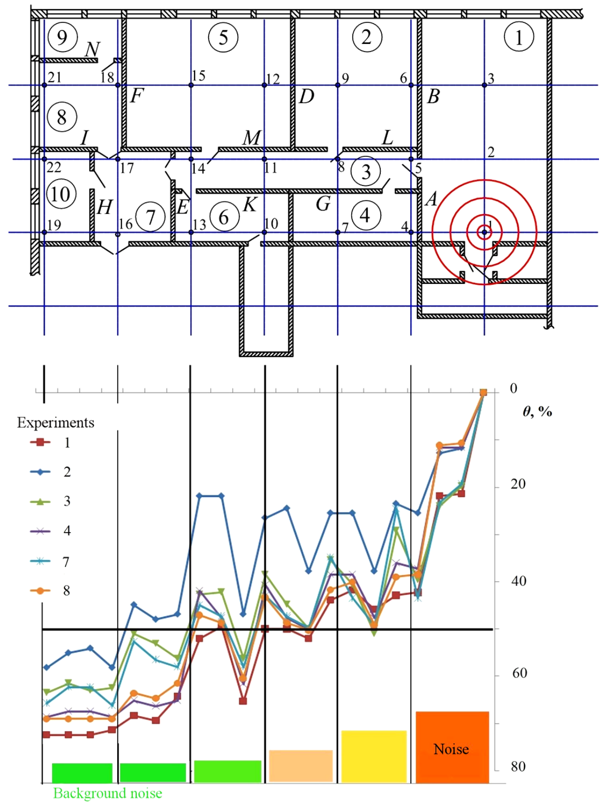

Fig. 8. Curves of the results of noise measurements in the experiments when the noise source was at point 1

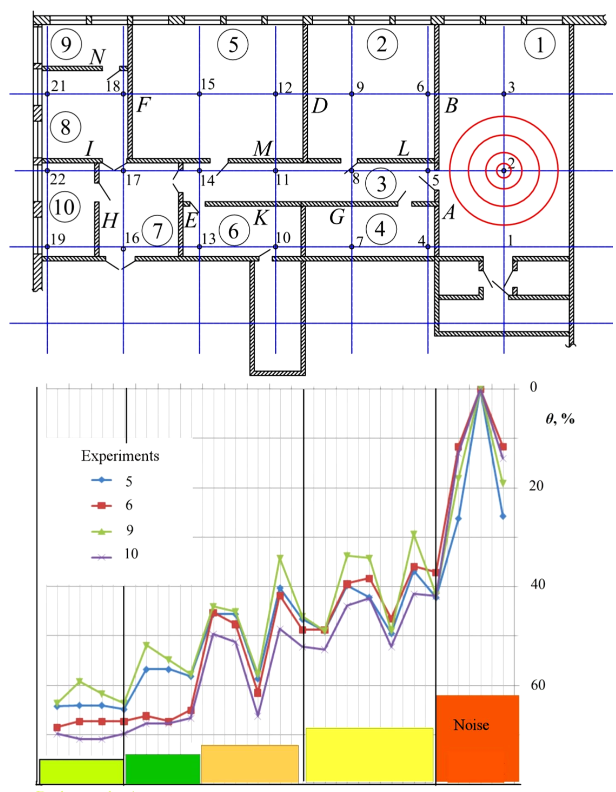

Fig. 9. Curves of the results of noise measurements in the experiments when the noise source was at point 2

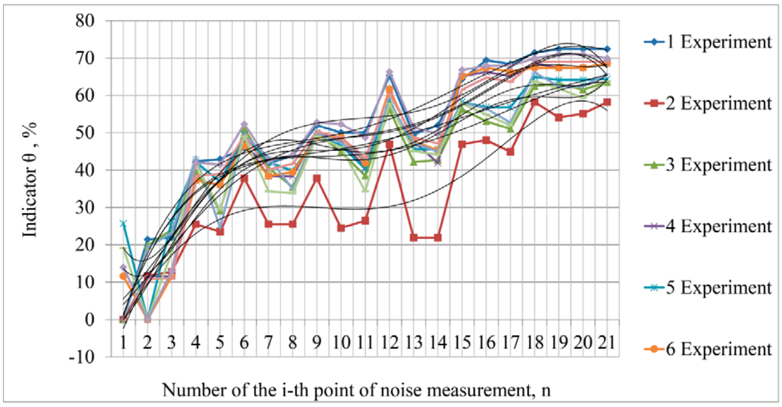

Fig. 10. Curves of noise distribution in the "Open space" office with partitions

Table 9 shows the polynomial dependences of noise curves trends according to the experiments.

Table 9

Polynomial dependences of noise curves trends

Number of experiment on noise level measurement, No.	Polynomial dependences of noise curves trends	Indicator R^2
1	y=0.0001x^5–0.0103x^4+0.3179x^3––4.3197x^2+27.801x–23.006	0.95
2	y=–0.0003x^5+0.0106x^4–0.1008x^3––0.5658x^2+11.772x–11.038	0.83
3	y=4E–05x^5–0.0056x^4+0.2137x^3––3.372x^2+23.794x–19.23	0.88
4	y=7E–05x^6–0.0045x^5+0.1136x^4––1.3051x^3+6.1484x^2–1.6415x–3.3493	0.91
5	y=0.0001x^6–0.0079x^5+0.2133x^4––2.7154x^3+16.268x^2–35.942x+41.468	0.83
6	y=–0.0004x^5+0.019x^4–0.3096x^3++1.6459x^2+4.3919x–1.6866	0.89
7	y=0.0001x^5–0.0106x^4+0.2973x^3––3.8886x^2+24.887x–19.945	0.87
8	y=–0.0002x^5+0.0086x^4–0.0649x^3––1.0082x^2+16.835x–18.161	0.93
9	y=0.0001x^6–0.0071x^5+0.1879x^4––2.3499x^3+13.789x^2–28.744x+30.816	0.81
10	y=–0.0005x^5+0.024x^4–0.4075x^3++2.3838x^2+2.9438x+0.6249	0.88

Acoustic characteristics of noise have logarithmic dependences, which are used in calculations by the standard. However, in the performed studies, we failed to obtain the trends with logarithmic indicators with high R^2, which is why we used approximation with the highest R^2, which were polynomial dependences of 5 and 6 orders. If in Fig. 10 we remove doors and vents, and these are the points that gave backbends of curves, we will have the form that is almost close to the logarithmic dependence.

Noise in premises without partitions

The study of noise propagation in the premises that are similar by all parameters, but without interior partitions was carried out. This study was conducted to compare the efficiency of using partitions and to find out the possibility to realize what was considered in experiment [32], when the noise level should be reduced to 50–51 (dBA). This interval was selected, because increased fatigue and decreased attention span of employees were observed at higher indicators.

Fig. 11 shows the results of measurements.

According to the experiments, the polynomial dependence of the trend of noise curve in premises, where there are no partitions, has the following form:

$$y=-0.0055x^3+0.2624x^2-4.4428x+93.894. \quad (7)$$

Indicator R^2=0.84. According to the curve in Fig. 9, it is possible to conclude that at the distance of point 21, that is 6·3.5=21 m, the noise level decreases from 96 to 66 dBA, that is by 30 dBA.

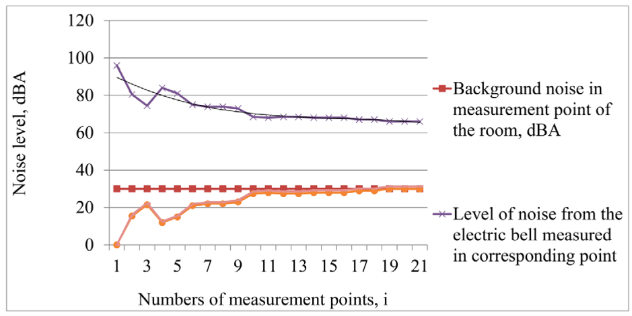

Fig. 11. Noise curve in premises without partitions

In the variant with the partitions, we have the same decrease at the distance of 4–6 points, behind one partition – at the distance of around 3–5 meters.

6. Discussion of research results

As a result of the research, dependences of the noise level in the "Open Space" premises ("OS") on the material and the degree of premises enclosure by height by partitions were found. This made it possible to determine the appropriateness of working areas formed by partitions, based on production tasks. That is why in zone 1 (Fig. 3), laboratory equipment with periodic noises of up to 100 dBA was located. In zones 2, 3 and 4, respectively, a laboratory office (variable work), a corridor and premises with periodically used office equipment were located. The lab equipment that had noise of up to 80 dBA was initially located in zone 2, but after the measurements and detection of its influence on other zones 5–10, it was relocated to zone 1. Effective soundproofing of working zone 1 was achieved thanks to the use of two-layer partitions with ceramic panels and 100 % enclose of the premises by height.

Analysis of the possibilities of noise reduction in the premises, when localizing the premises and working areas with the noise source using partitions, revealed that noise localization should be made taking into consideration the direction of noise from the source, in this case not only frontal impacts, but also lateral are possible due to open holes in partitions and ventilation ducts (Fig. 8, 9). They significantly affect coefficient of noise attenuation and decrease it.

Detection of noise propagation at different states of openings in the partitions (doors, vents, etc.) in the premises at its 100 % enclosure and less by height made it possible to conclude that the addition to the existing partitions in premises with semi-enclosure by height (75 %), but with the density of material of more than 2,500 kg/m^3 (enclosures are designated in Fig. 3 and Table 2 with numbers *L* and *M*), of other material that ensures complete enclosure (density up to 1,000 kg/m^3), makes it possible to increase the overall effect of noise reduction to that of ceramic partitions B and A (Fig. 3). That is, to reduce noise by 30–40 dBA.

Comparative analysis of noise propagation in the premises without and with partitions revealed that partitions have a significant effect on noise attenuation (θ (4) %). The best effect is achieved by installing more than 2 partitions across the direction of sound wave propagation relative to the noise source. Thus, it is advisable to locate offices according to possible noise sources behind the partitions at the distance of more than 3.5 m (Fig. 7).

The drawback of the research is limited materials of partitions that were explored in the experiment. Three types of partitions were used: heavy-weight – ceramic panels (density of about 2500 kg/m^3), medium-weight – glass pipes (density of about 1,500 kg/m^3) and light-weight – foam plastic (density of less than 1,000 kg/m^3). The limited working space and financial constraints did not make it possible to conduct research on other materials.

An analysis of research results has revealed a decrease in psycho-acoustic effect on employees and these results inspire to experiment in that direction. It was also noted that the impact of the noise from working computers and office equipment, intended for printing, decreased significantly.

In the performed studies, we obtained the answer to the question of detection of the drawbacks in already installed partitions and their improvement according to the set productive tasks in the office premises and the existing sanitary-and-hygienic requirements.

7. Conclusions

1. It was established that the noise indicators in "Open space" workstations depend on the type of partitions and the degree of premises (workstation). Thus, it is necessary to make a well-grounded selection of partitions depending on the categories of work and functional purpose. If the noise is of more than 80 dBA (sound frequency ≈1,000 Hz), it is necessary to isolate the working area of an office with heavy-weight partitions made of ceramics or brick. For areas where noise in the premises fluctuates from 50 to 80 dBA (sound frequency ≈200÷500 Hz), it is necessary to install a medium-weight partition made of glass or wood, to bring the noise indicators values to the level of background noise. The best noise reduction effect was obtained at 100 % enclosure of one workstation from another by the partition.

2. For the purpose of efficient and rational use of partitions, it is necessary to reduce noise in the premises through the use of heavy-weight partitions localizing the zone with the noise source. For other areas of the room, where people are working, it is possible to separate them based on functional features of work with medium-weight and heavy-weight indicators. In this case, the premises enclosure by height should be 75–100 %.

3. While locating partitions, we recommend taking into consideration all the ventilation openings that unite all separated areas, windows enclosures, etc. The presence of such openings can negate the protective properties of partitions. At 100 % enclosure of premises by height with the help of partitions, it is necessary to make the own air vents or install air conditioners (split system), based on the calculation of ventilation of premises, in order to obtain meteorological parameters relevant to the work performed.

4. Given the need to optimize the ratio of the partition price and production tasks, it is necessary to apply a scientific approach when conducting the analysis of acoustic insulation of the installed partitions using grid putting on the layout of the premises with the distance between the measurement points that correspond to the sound wave line in the OS office, specifically, 3.5 m.

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