The influence of finishing materials on the formation and propagation of acoustic resonant waves from external sources of noise in a closed room

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Abstract. The analysis and selection of the optimal finishing building materials according to the criterion of influence on the formation and propagation of acoustic resonant waves from the external sources of noise in a closed space have been carried out. The buildings located directly on the red line or at a distance of up to 100m from the roadway get most of the acoustic pressure from motor vehicles. Exceeding the permissible norms is especially often observed during the rush hours and on weekends. Acoustic waves, getting into the room and partially reflected from the enclosing structures create a resonance negatively affecting people in the room. This problem can be partially solved by the correctly-chosen home decoration materials, which have an absorption coefficient at average frequencies greater than 0.2 at geometric frequencies of 500-4000 Hz.

Introduction
A person spends more than 2/3 of his life indoors that is supposed to ensure a comfortable and safe stay of a person there. The main requirements for the room are: the microclimate of the environment, insolation, the level of noise and vibration, the level of radiation. In the previously conducted study, the results of which are reflected in [1,2], it is shown, that the noise load on city streets exceeds the permissible norms. The buildings located directly on the red line or at a distance of up to 100m from the roadway get most of the acoustic pressure from the motor vehicles. Exceeding the permissible norms is often observed during the rush hours and on weekends. The noise from the car is often mixed with the domestic, coinciding in frequency causes an amplified resonant wave. The sound wave formed on the street, partially or completely falls through the enclosing structures in the room, thereby provoking acoustic excitation of humans. From a physiological point of view, noise refers to any unwanted sound or combination of sounds that has an irritating effect on the hearing organs. Noise is a general biological irritant and adversely affects the individual organs and systems of a person, especially the nervous and cardiovascular systems. Noise at night is especially dangerous, interrupting sleep, it can cause chronic insomnia, weakness, irritability, all sorts of neuroses. Day nap is necessary in preschool educational institutions, medical and health-improving institutions. Therefore, the study of this issue acquires particular relevance in the resort cities and in the city residential areas, where kindergartens and hospitals are located, where regular airing is required according to the regulatory requirements.

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Thus, one of the main qualities of the premises can be called sound insulation from the aggressive effects of the external noise. Under sound insulation it is to reduce the pressure level of the incoming sound by passing the acoustic waves through any obstacle, for example, through the building envelope. It is necessary to reduce the incoming acoustic impact to comfortable standard values in the places where people stay.

The low level of construction and installation works in new buildings and physical deterioration of the main structures in buildings of early construction leads to the fact that the level of sound insulation in the main part of urban buildings does not meet regulatory requirements. Because of this, it is necessary to organize additional sound insulation in the premises, including using modern soundproof finishing materials.

Main Part
Research in the field of sound insulation, sound absorption and sound reflection started about 20 years ago. Until that time the object of the sound-insulating, sound-absorbing, sound-reflecting characteristics study of building materials had not been carried out.

Professor I.L. Shubin deeply studied this question. His works [3,4] and scientific activities are devoted to the topic of sound insulation and noise absorption in urban areas [5,6] with an assessment of the influence of reflected sound energy on the noise mode of residential development, as well as improving methods for calculating the expected indoor noise sound-absorbing cladding, methods of acoustic calculation and design of acoustic screens with the compilation of noise maps to assess the acoustic pollution of the cities [7,8].

In terms of the environmental safety of the city’s territories from the noise pollution, as well as the influence of noise on a person was studied by the authors: V. Azarov, N. Bakaeva, I. Shishkina, M. Klimova, E. Stepanova, E. Domanova A., Shestakov O.V., Kharlamov A.P., Sannik A.O., Minin N.N., Dokshin M.S., Sidyakin P.A. and others [9-11].

The formation of the noise exposure in the workplace, the development of the protective measures with the stationary equipment involved the following researchers: Gotlib Ya.G., Zamshin V.A., Belyakov A.A., Karazhdi S.V., Kobzev K.O., Preobrazhenskaya E. A., Drozdova N.V., Gagarin D.R. and others [12,13] into a deep study of this problem.

The development of methods and tools for predicting the structural noise of an internal combustion engine and methods of acoustic refinement of a car by external and internal noise were done by the researchers: Yakovenko A.L., Drobakha M.N., Terentyev A.N., Safin A.I., Plitsyna OV, Petrov A.A., Bangoyan E.G., Malkin I.V., Krasnov A.V., Yakovenko A.L., Krichevskaya T.Yu. and others. [14]

In recent years the scientific research has not paid attention to the study of the provision of Technosphere safety in a room from the point of view of the influence of finishing materials on the formation and propagation of acoustic resonant waves from the external noise sources in a closed room. This is the reason for the relevance of the topic of the given article.

The goals and objectives
The aim of the work is to analyze and determine the level of influence of finishing materials on the formation and propagation of acoustic resonant waves from the external noise sources in a closed room. Among the main tasks it is necessary to highlight the following: to identify the level and the form of noise from the urban road transport streams, to consider the propagation of acoustic resonant waves in the room, to systematize the finishing materials according to the type of application, to improve the sound insulation qualities of the room, to give recommendations for optimizing the level of acoustic climate in closed rooms.

The main characteristic of the noise level can be called the sound intensity level $L$, which is measured in dB. The range of the main acoustic stream that a person hears varies from 20 to 140 dB. The increased frequency, intensity of the incoming sound stream have negative effect on the human body, the higher these values are, the worse are the effects of noise on the body. Noise with a sound pressure level of up to 30–40 dB is familiar to people and comfortable for the hearing organs. An
increase to 45–70 dB forms a significant load on the human nervous system and provokes poor health and with the prolonged exposure may contribute to the development of diseases of the hearing aid. Exposure to intense noise levels above 75 dB provokes the development of partial hearing loss [13]. The sound from 120–130 dB causes pain and damage to the human hearing system. Under the noise effect with a sound pressure level of 140–160 dB, rupture of eardrums and contusion are possible. [15]

Most often, there is a mixed type of noise in the room. The sources of noise in the room include sounds of street transport, sewage, air ducts, technical equipment, audio-video equipment, household appliances, human speech, etc. It is accepted to separate types of noise on air and structural ones. Airborne noise (the propagation medium is air), people’s talk can be attributed to such a noise. Structural noise (the propagation medium is a solid), for example, a hammering sound.

The standard values to be measured according to ISO are:

- Sound pressure level Lp, dB;
- A-corrected sound level LA, dBA.

The intensity of the incoming noise in the room can be measured. Different types of ground transport have an intensity of the sound exposure from 70 to 100 dB.

Our measurements on the streets of the resort town Pyatigorsk [1.9] showed the of urban noise level ranging from 66 dB to 85 dB. Acoustic wave emanating from the motor stream, mixed with the household noise, coinciding in parameters (frequencies), causes an amplified resonant wave.

The studies show that in modern civilian buildings the sound insulation properties of enclosing structures do not always comply with the regulatory requirements for sound insulation. The same situation is observed in existing buildings of urban development due to the deterioration of structures and the loss of the required soundproof qualities, and because of changes in the composition, structure and increase in the amount of incoming noise.

For the formation of a favorable acoustic climate in the premises of a civilian building it is necessary to take additional measures for the sound insulation, which is determined by the ability of the enclosing structures (walls, partitions, ceilings, etc.) to reflect or absorb the air, impact miles structural noise.

According to the current norms SP 51.13330.2011 “Protection against noise” [16] soundproofing of internal walling is characterized by the measured parameters:

- Airborne sound insulation index RW, dB;
- Index of the reduced impact noise level (isolation of impact noise) LW, dB [16].

Normative index values vary depending on:

- Appointment of a civilian building and its functions;
- Provided comfort conditions;
- Type of enclosing structures.

Ensuring the necessary acoustic comfort of the premises is possible by the implementation of acoustic construction measures to protect against the external and internal noise, among them: optimal architectural and planning solutions, the use of natural and artificial acoustic screens, the introduction of sound absorbing and sound scattering structures and so on.

One of the most rational and appropriate methods to ensure the acoustic climate in the room is the use of sound-proof and sound-absorbing finishing materials due to the simplicity of installation, accessibility and lower labor intensity.

Finishing materials have different properties in terms of sound absorption and sound reflection. It depends on the type of the material, its processing, structure, thickness and other characteristics. In this regard, finishing materials absorb and reflect incoming sound waves in different ways. This is especially important in a closed room with the windows open (in summer or at the request of sanitary standards).

It is known that the sound energy, entering the room is partially reflected from the walls (Uotr1), the ceiling (Uotr2) and the floor (Uotr3) and is partially absorbed by them. The reflected energy can be determined from the following equations:

\[ U_{refl} = U_{fall} \cdot U_{abs} = U_{fall} \cdot a_i \cdot U_{fall} = U_{fall} \cdot (1 - a_i), \quad (i = 1, \ldots, 3). \] (1)
where: $a_i$ – is the absorption coefficient of the $i$-th object (boundary); $U_{fall,i}$ is the sound energy falling on the $i$-th object; $U_{abs,i}$ is the absorption energy of the $i$-th object.

Let us consider the formation of the boundary conditions for numerical calculations with different values of the absorption coefficient.

**Figure 1.** Object discretization scheme

Figure 1 shows the sampling scheme of the object under consideration.

Sampling points: coordinate $x: 0 \leq n \leq N_x$, sampling step $\Delta x = L_x / N_x$; on the $y$ coordinate $0 \leq n \leq N_y$, the discretization step is $\Delta y = L_y / N_y$; on the $z$ coordinate $0 \leq k \leq N_z$, the discretization step is $\Delta z = L_z / N_z$. Let us consider the side face. Let us assume that the acoustic effect acts indoors, the discrete analogue of which is $U_{n,v,k}$. The behavior of the acoustic impact on the considered edge (at the boundary, for a given absorption coefficient ($a_i$)), in accordance with (1), is written as follows:

$$U_{n,v=0,k} = U_{n,v=1,k} \cdot (1 - a_i), \ (n=1..N_x-1, k=1..N_z-1),$$

(\text{where: } U_{n,v=1,k} \text{ is the sound energy falling on the face; } U_{n,v=0,k} \text{ is the reflected energy;})

if the boundary is perfectly absorbing ($a_i=1$), then $U_{n,v=0,k} = 0, \ (n=1..N_x-1, k=1..N_z-1)$;

if the boundary is perfectly reflective ($a_i=0$), then $U_{n,v=0,k} = U_{n,v=1,k}, \ (n=1..N_x-1, k=1..N_z-1)$.

The boundary conditions of the above-described options can be described when simulating various acoustic processes.

Table 1 presents the materials and the corresponding sound absorption coefficients in octave bands with geometric average frequencies, these materials are detailly presented in [17].

**Table 1.** Finishing materials and corresponding sound absorption coefficients in octave bands with geometric mean frequencies of 125–4000 Hz [16].

| Building material or construction | Sound absorption coefficient $a$, in octave bands with geometric average frequencies, Hz |
|----------------------------------|----------------------------------|
|                                  | 125    | 250    | 500    | 1000   | 2000   | 4000   |
| Wall decoration                  |        |        |        |        |        |        |
| Concrete                         | 0.01   | 0.01   | 0.02   | 0.02   | 0.04   | 0.04   |
| Concrete painted with oil paint  | 0.01   | 0.01   | 0.01   | 0.01   | 0.02   | 0.02   |
| Wood paneling, (pine) 19 mm thick| 0.1    | 0.1    | 0.1    | 0.08   | 0.08   | 0.11   |
| Wood panel with a thickness of 5 - 10 mm with an air gap of 50 mm | 0.25   | 0.15   | 0.06   | 0.05   | 0.04   | 0.04   |
| Wooden plates                    | 0.12   | 0.11   | 0.1    | 0.03   | 0.08   | 0.11   |
| Chipboard in contact with the base| 0.01   | 0.09   | 0.09   | 0.08   | 0.09   | 0.14   |
| Brickwork without jointing       | 0.15   | 0.19   | 0.29   | 0.28   | 0.38   | 0.46   |
| Material Description                                                                 | 0.15 | 0.19 | 0.21 | 0.28 | 0.38 | 0.46 |
|-------------------------------------------------------------------------------------|------|------|------|------|------|------|
| Brickwork in the blank seam                                                         |      |      |      |      |      |      |
| Brickwork with jointing                                                             | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 | 0.06 |
| Brickwork with jointing, painted with oil paint                                     | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 |
| Brickwork with jointing, plastered                                                  | 0.02 | 0.02 | 0.02 | 0.03 | 0.04 | 0.04 |
| Masonry with jointing                                                               | 0.03 | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 |
| Brick wall, unplastered                                                              | 0.02 | 0.03 | 0.03 | 0.04 | 0.05 | 0.07 |
| Brick wall, plastered and painted with oil paint                                    | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.03 |
| Wall, plastered and painted with oil paint                                          | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 |
| Wall plastered with lime with metal mesh                                            | 0.04 | 0.05 | 0.06 | 0.08 | 0.04 | 0.06 |
| Wall plastered with lime with metal and wooden mesh                                 | 0.03 | 0.05 | 0.06 | 0.09 | 0.04 | 0.06 |
| Sand lime wall                                                                      | 0.04 | 0.05 | 0.06 | 0.09 | 0.04 | 0.06 |
| Acoustic gypsum-pumice plaster                                                      | 0.12 | 0.27 | 0.31 | 0.32 | 0.38 | 0.4  |
| Acoustic plaster of burnt kaolin crumb                                              | 0.11 | 0.13 | 0.33 | 0.49 | 0.29 | 0.35 |
| Acoustic plaster made of finely granulated mineral                                   | 0.21 | 0.29 | 0.42 | 0.48 | 0.47 | 0.45 |
| Acoustic Cement Pumice Plaster                                                     | 0.12 | 0.27 | 0.31 | 0.31 | 0.33 | 0.4  |
| Acoustic cement slag plaster                                                       | 0.08 | 0.16 | 0.23 | 0.3  | 0.32 | 0.35 |
| Acoustic cement-pumice plaster                                                     | 0.27 | 0.31 | 0.31 | 0.31 | 0.33 | 0.4  |
| Gypsum plaster                                                                      | 0.04 | 0.04 | 0.04 | 0.06 | 0.06 | 0.03 |
| Gypsum smooth unpainted plaster                                                    | 0.013 | 0.015 | 0.02 | 0.028 | 0.04 | 0.05 |
| Gypsum smooth painted plaster                                                      | 0.012 | 0.013 | 0.017 | 0.02 | 0.023 | 0.025 |
| Rough lime plaster                                                                  | 0.025 | 0.045 | 0.06 | 0.085 | 0.043 | 0.058 |
| Dry plaster                                                                         | 0.02 | 0.05 | 0.06 | 0.08 | 0.05 | 0.05 |
| Dry plaster at a distance of 5 cm from the surface                                  | 0.3  | 0.25 | 0.15 | 0.08 | 0.05 | 0.05 |
| Sheets of dry gypsum plaster on beacons                                             | 0.02 | 0.05 | 0.06 | 0.08 | 0.04 | 0.06 |
| Floor finish                                                                        |      |      |      |      |      |      |
| Parquet on asphalt                                                                  | 0.04 | 0.04 | 0.07 | 0.06 | 0.06 | 0.07 |
| Parquet on a wooden base                                                            | 0.1  | 0.1  | 0.1  | 0.08 | 0.06 | 0.06 |
| Wooden plank floor                                                                  | 0.15 | 0.11 | 0.1  | 0.07 | 0.06 | 0.06 |
| Floor boardwalk logs                                                                | 0.1  | 0.1  | 0.1  | 0.08 | 0.08 | 0.09 |
| The floor on wooden beams                                                           | 0.15 | 0.11 | 0.1  | 0.07 | 0.06 | 0.07 |
| Parquet floor (on asphalt)                                                          | 0.04 | 0.04 | 0.07 | 0.06 | 0.06 | 0.07 |
| Floor mastic rubbed on wooden beams                                                 | 0.15 | 0.11 | 0.1  | 0.07 | 0.06 | 0.06 |
| Non-lacquered cork, 3 mm                                                            | 0.02 | 0.02 | 0.05 | 0.1  | 0.25 | 0.15 |
| Carpet covering                                                                     | 0.08 | 0.08 | 0.2  | 0.26 | 0.27 | 0.37 |
| Linoleum                                                                            | 0.02 | 0.02 | 0.03 | 0.03 | 0.04 | 0.04 |
| Laminate                                                                            | 0.05 | 0.04 | 0.07 | 0.07 | 0.07 | 0.07 |
| Parquet on glue                                                                     | 0.04 | 0.04 | 0.07 | 0.07 | 0.07 | 0.07 |
| Parquet on the keys                                                                 | 0.2  | 0.15 | 0.12 | 0.1  | 0.08 | 0.07 |
| Marble, granite, etc.                                                                | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 |
| Doors                                                                               |      |      |      |      |      |      |
| Massive door                                                                        | 0.14 | 0.1  | 0.06 | 0.08 | 0.1  | 0.1  |
| Lightweight cellular door                                                            | 0.25 | 0.2  | 0.15 | 0.1  | 0.08 | 0.07 |
| Door with glass                                                                      | 0.25 | 0.2  | 0.1  | 0.05 | 0.04 | 0.05 |
| Glass door, 8 mm                                                                    | 0.18 | 0.06 | 0.04 | 0.03 | 0.02 | 0.02 |
The materials in which the absorption coefficient at mid frequencies is greater than 0.2. show the high sound-absorbing qualities. As shown by the experimental studies [1], the main excess of normative values in the territory of urban development is concentrated in the average geometric frequency of 500 - 4000 Hz. Therefore, when determining the optimal finishing materials, the priority is given to the materials whose sound absorption coefficient is maximum in this range. The choice and application of any sound insulation materials depends on the purpose of the room. It is conditionally possible to distinguish the following categories: office, industrial, residential, public premises. Each of them has its own regulatory requirements for finishing, depending on the purpose and specificity of the room. In the practice of civil engineering, four main areas of sound insulation in the internal space of a building can be distinguished: sound insulation of walls and interior partitions, protection of floor construction, floors and joints with walls, window doors, sound insulation of utilities that can serve as conductors and noise sources. So, for the finishing of the room, it is necessary to select finishing materials, in which the absorption indices are maximum at geometric average frequencies of 500 - 4000 Hz (Table 2).

Table 2. Approximate list of home decorative materials recommended for the maximum sound absorption in average geometric frequencies of 500 - 4000 Hz

| Material or design                  | Sound absorption coefficient α, in octave bands with geometric average frequencies, Hz |
|-------------------------------------|------------------------------------------------------------------------------------------|
|                                     | 125 | 250 | 500 | 1000 | 2000 | 4000 |
| Wall decoration                     |     |     |     |      |      |      |
| Acoustic plaster made of finely     | 0.21 | 0.29 | 0.42 | 0.48 | 0.47 | 0.45 |
| Floor finish                        |     |     |     |      |      |      |
| Parquet on the keys                 | 0.2 | 0.15 | 0.12 | 0.1  | 0.08 | 0.07 |
| Doors                               |     |     |     |      |      |      |
| Lightweight cellular door           | 0.25 | 0.2  | 0.15 | 0.1  | 0.08 | 0.07 |
| Windows                             |     |     |     |      |      |      |
| Glazed window covers               | 0.35 | 0.25 | 0.18 | 0.12 | 0.07 | 0.04 |

Summary

The analysis and selection of optimal finishing building materials according to the criterion of influence on the formation and propagation of acoustic resonant waves from the external sources of noise in a closed room has been carried out. When choosing the home decorative materials for the optimal resonant waves’ absorption, first of all it is necessary to pay attention to the sound insulation performance (determined by the insulation index of the airborne noise (RW, dB)) and the sound absorption (determined by the sound absorption coefficient (α)). The closer the sound absorption coefficient to unity is, the better are its protective properties against the acoustic effects in the room.

Home decorative materials should be considered as a part of a further research from the point of view of absorbing sound impact types, to simulate the process of forming acoustic resonant waves in a closed room, depending on the type of the decorative materials, to consider how saturation of residential and public furniture and interior objects is affected by the external sources of noise in a closed room.
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