Analysis of the noise load from the manufacturing enterprise on the territory of residential buildings based on complex mathematical model

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Abstract. Noise is known to be one of the most common negative factors that can have detrimental effect on human and the environment. In the article the expected noise load on the territory of a residential development located in the immediate vicinity of a metallurgical plant is analyzed. A steel arc furnace is taken as an active source of noise. Account has been taken of the main techno-economic, structural and social indicators of the situation in which housing development has been organized in close proximity to existing industrial plants. All the data obtained from studying the propagation of noise from the source are processed on the basis of the complex mathematical model in the PTC Mathcad Application. The model makes it possible to carry out studies of distribution of the air noise of an active industrial source in multifunctional areas, to carry out calculations in accordance with the established normative methods, and to analyse the CPD over the whole frequency range. It is also possible to analyse the application of the most effective ways of reducing acoustic load. The most effective engineering solution is a complex screening scheme which makes it possible to reduce the sound pressure levels of the frequency range from 20Hz to 10 000Hz by 20-25 dB, thus satisfying the modern requirements of sanitary standards for residential development.

1. Introduction
Making sustainable cities would require implementation of complexed measures to mitigate impact of the dangerous and harmful factors on the population and environment. Noise (acoustic) pollution human origin is one of the factors physical nature which violating livelihoods of living beings and human.

According to the degree of harm, the noise pollution is the second only to the pollution. This was because effects on the human, noise has the potential to cause a number of serious symptoms, which human rare associated with noise load: rapid lassitude, dyspnea, tachycardia, arterial hypertension (high blood pressure), heartache, disruption of digestive tract, mental disorder, diminished hearing etc. Among described symptoms, doctors diagnosed as noise sickness [5, 13-15].

The main sources of noise on the residential’s territory are full range of the transport (auto, aero, rail vehicle) and manufacturing enterprises. Its contribution is approximately 80% of overall noise. The other 20% accounts for household noise [7].

The successful fight against transport noise in cities provided by complex underground space development, evolvement underground system, highway and railway tunnels [6].
Noise influence of manufacturing enterprises to the nearby residential areas remains under research. Furthermore, manufacturing enterprises make up 30% of urban spaces [6-12, 16-18].

Method of facility guard plot from green planting is among the most financially and environmentally handsome ways to cut noise influence from manufacturing enterprises to the urban environment. Thus, in the article of J. A. Gordeeva and A. A. Kulagina approves increased noise-protective ability of mixed plantation of several layers [9]. The number of tree crowns - the second most important influence. A serious decrease of protective properties of the green plantations noted in autumn and winter [9].

Whereas, J. A. Vinnikov, has pointed that figures of noise absorption properties dependent on sizes its leaf blades, highlights other patterns, e.g. largest significance factors of the noise absorption have broad-leaved species like horse chestnut [10]. The author also provides information that confirms increasing of noise-protective properties of the green plantations with rising longitudinal disruption in the belt [10].

Generally, as the analysis of scientific researches and practical experience shows that provides effective noise protection that can be used belts of the green plantations over manufacturing enterprises is impossible. Implementation of combined decisions is necessary, particularly joint application of green belts and acoustic screens. Purpose of the present research is a validation of optimal parameters such systems [18-19].

2. Materials and methods

Complex mathematical modelling completed for explore process of noise dissemination from source, located on the area of manufacturing enterprise and validation of optimal parameters of combined protective systems. The model has developed in the software environment, PTC Mathcad Application, and has optimized to solve main engineering challenges during implementation of the acoustic calculation [1-3, 8].

Integration of the acoustic calculations in the program environment of Microsoft Excel and Mathcad Application in this case on the borders of health protection zones, produces graphical, mathematical models of unique sources of sound fields. Model allows produce calculations according to the established normative methodologies for analyzes across frequency rate. Analysis of the most effective ways of implementing for reducing acoustic load possible in the Mathcad environment, based on modelling noise field.

The formula (1) served as a calculated basis of the mathematical model to identify level of the sound pressure $L_{P}$, dB from I sound source at any point in the territory in question for every of octave band [4,5]:

$$L_i = L_{P} + 10 \log \left( \frac{r_{1} + (1 - \alpha) \Phi_{1}}{\Omega} \right) - 10 \log \left( \frac{r_{2} \beta_{a}}{1000} \right) - \Delta L(H) - \Delta L(B) - \Delta L(F),$$  \hspace{1cm} (1)

where: $L_{P}$ - the octave level of acoustic power noise source dB, located on the facilities;

- $K$ - dimensionless coefficient;
- $r_{1}$ - distance in metres between source of noise and calculation point;
- $r_{2}$ - distance in metres between mirror image source of noise under reflection from the surface and calculation point;
- $\Omega = 4\pi$ – complete spatial angle in steradian;
- $\alpha$ – octave sound-absorbing coefficient of the surface – is assumed to 0.1 – for solid surfaces (asphalt, concrete) and 0.3 – for grass and snow cover;
- $\beta_{a}$ – octave sound damping coefficient in atmosphere along 1 km;
- $\Phi_{1}, \Phi_{2}$ – directivity coefficients of rays noise source and its mirror image;
- $\Delta L(B)$ – noise reducing in dB when screens are located between noise source and calculation point;
- $\Delta L(F)$ – reducing sound level by the belts of the green plantations or forest area;
\( \Delta L(H) \) – correction in dB, including sound isolation of the open window construction \( \Delta L(H)=10 \) dB. Correction used when calculation point is inside residential building.

Modelling provided in several steps:
1. Identify of noise levels without protection systems.
2. Identify of noise levels with acoustic screen.
3. Identify of noise levels when changing high of acoustic screen.
4. Identify of noise levels when changing wide of protection belt.

The large enterprise of Rostov region accepted as an object of the research – Taganrog’s metallurgical plant and area adjacent to the plant.

As a result of analysis of equipment’s noise characteristics chosen the most active object – steel-smelting arc furnace – 150, commissioned in 2013.

Site plan of research area is presented on the Picture (Fig. 1). The minimal distance from noise source to essential facilities of residential development is of 39 to 115 m.

The calculations of noise pressure levels are produced in points according to the location of residential developments at the distance 50, 150, 300, 500 and 1000 m.

![Figure 1. Site plan of positioning of noise source and neighboring residential construction](image)

3. Results
Reported values of sound pressure level at varying distances from the noise source and maximum permissible levels (MPL) for different center frequencies are presented on Fig.2.
The following conclusions made after the analysis of the received data:
- in comparison with the norms of darkness hours, the excess is observed practically at all frequencies and distances to the calculated points (CP) and ranged from 2 to 35 dB;
- for daily quota, the excess is observed in all CP in the range of medium and high frequencies and ranged from 2 to 25 dB;
- SPL peaks are observed at medium frequencies, that the human ear is most sensitive.

At the second stage of the study, the SPL parameters are determined taking into account the established screen with a maximum height of 14 m. The results of calculations in the form of graphs are shown in Fig. 3.

The following conclusions can be drawn from the obtained graph:
- in the presence of a screen with a height of 14 m in the residential area during the daytime, noise standards are observed;
- at darkness hours, noise levels are exceeded in the CP at distances of 50 and 150 m (at this distance the residential development is located) at the central frequencies from 500 to 2000 Hz.

To ensure compliance limits at night may be achieved by increasing the height of the protective screen or the device of the protective belt from the green plantations on the path of sound from the noise source.

Due to the fact, that the maximum elevations of the SPL over the night limits were observed at medium frequencies, the calculation of SPL with a change in screen height was made for the average central frequency of 1000 Hz and the distance from the noise source is 50 m. The simulation results are shown in Fig. 4.
From Fig. 4 it can be seen that the achievement of ultrasound that satisfy the remote control at a distance of 50 m from the noise source for the darkness hours of the day occurs only at a screen height of 24 m. However, the construction of an acoustic screen of this height is structurally difficult and economically unsuitable.

In the next stage of the research, a calculation of the SPL was performed when the length of the belt of green plantations was changed. The results of this calculation are summarized in the graph shown in Fig. 5.

The given graph allows to give the recommendations justified of calculations that in order to comply with the noise control at night, belt of green plantations with a total length of at least 30 m is required. However, the maximum possible depth of plantations along the path of sound from the noise source to the residential development is 15-20 m. Therefore, solution, a combined protection system can be recommended, including an acoustic screen 14 m high and a protective strip of green spaces 15 m wide. With these parameters, it is ensured that remote control at a distance of 50 m from the noise source at darkness hours.

4. Conclusions

Based on the completed researches, the following conclusions can be drawn:

1. The developed integrated model is adequate and allows further researches of air noise distribution of an active enterprise source in multi-functional areas, also taking into account the proposed engineering solutions (utilization of various materials, changing geometric parameters and screen shapes);
2. The expected noise load of the steel-smelting arc furnace chipboard -150, in the presence of an acoustic screen, exceeds the noise control at darkness hours in residential area;

3. Decrease of SPL on the territory of residential development to the standard indicators possible with increasing the height of the acoustic screen to 24 m, which isn’t constructive and economically feasible, or expanding the protective belt of green plantations to 30 m, which is impossible due to lack of free territory;

4. As an optimal solution, a combined protection system can be recommended, including an acoustic screen 14 m high and a protective belt of green plantations 15 m wide. With such parameters, the limits are enforced at a distance of 50 m from the noise source at darkness hours.

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