Protection Against Traffic Noise Acoustic Screens with Solar Cells

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Abstract. In connection with the growth of cities and the increase in building density, the problem of noise control in the city is becoming increasingly relevant. To protect residential areas from the noise of traffic flows in megacities, acoustic barriers with their own design features are widely used. These features can be based on a number of reasons: a complex noise picture, imperfection of noise insulation or noise absorption materials, high cost of execution, and other reasons. The article shows that the use of transport acoustic barriers with hoods, the design of which includes solar panels, can ensure the investment attractiveness of highway projects due to the potential profit from the use of solar energy. The efficiency of the use of solar cells in the construction of transport acoustic barriers is evaluated on the example of protection against exceeding the permissible noise of a section of territory near a major highway in St. Petersburg. The necessary noise measurements were carried out and a 3D model of the highway section was created with an acoustic barrier design that combines the function of noise reduction and solar energy generation. The selection of the tilt angle of the hood of the acoustic transport barrier was carried out (it was proposed to place solar panels on the hood), when the use of solar energy in the territory of St. Petersburg and the Leningrad region is sufficient to generate adequate electricity consumption in the period from April to September. To assess the effectiveness of the protective barrier, we used guidelines for protecting areas adjacent to highways from traffic noise from Rosavtodor for galleries and tunnels. The conducted assessments showed the prospects of using solar cells in the construction of transport acoustic barriers, as it is shown that even in geographical locations with relatively low solar activity, a useful effect can be obtained from the use of solar panels.

1. Introduction
In major megacities noise pollution is a serious problem, what is more, it has been established that the main source of the noise is traffic. The level of the noise generated by traffic is growing due to cities expanding and the urban density increasing, so the issue of fighting the noise in the city is becoming more and more relevant. The noise produced by transportation highways spreads not only through the territories adjacent to the highways, but also deep into residential developments. Some parts of residential blocks and microdistricts located near municipal highways are in the zone of the strongest noise exposure. To enable protection from the city noise, it is necessary to regulate its intensity,
spectral composition, impact time and other parameters. In large cities, there is high percentage of load-carrying vehicles on highways. The increasing number of load-carrying vehicles, especially large-capacity diesel-powered ones, in the general traffic amplifies the noise levels. In order to protect the territories from increased noise levels, various measures are being introduced such as reorganisation of territories, installation of acoustic barriers at highways, setting up plant barriers, rational organisation of traffic, building depressed express highways, etc. [1-3].

Installation of acoustic barriers along the roads is one of the most common solutions to fight the noise from traffic, but quite often, they exhibit only partial efficiency in performing the imposed protective task [4-5], which can be explained by the imperfections in sound insulation methods and costliness of the projects. For instance, in St. Petersburg the cost of an acoustic barrier per one square meter is 21,000 roubles, including the mounting costs [6]. Such a high cost of projects entails the task of finding ways to cheapen them, which cannot be solved through sacrificing the acoustic efficiency. One of the possible means to reduce expenditures for the installation of acoustic barriers might be to gain profit from the use of solar energy through integrating solar cells into the design of the barriers. The study of BIPV (building-integrated photovoltaics) predicts the growth of the solar energy sector in the global power industry and increase in energy produced by solar-powered facilities [7-8].

Thanks to their geographical location, a number of countries have high potential to use solar energy and are beginning to explore this energy source, looking for so-called 'hot spots' [9-16]. Using solar energy can help lower the dependence of the countries on imported fuels. The assessment of the potential of using solar power on the territories of the Russian Federation is only making its start [17]. The operation of solar cells has shown the necessity to monitor the state of panels' coating, since the application of, for example, a graffiti onto solar panels can decrease the amount of power generated by said panels [18], it has been proposed to apply 'anti-graffiti' coating. This solution does not eliminate all of the issues, since it also rises the price of the project and the problem of cleaning-up the panel surfaces still remains. Developing solar-powered acoustic barriers presupposes analysis of the existing projects [19-20] to accumulate certain knowledge on their operation and ensure the required noise reduction in urban areas can be achieved as well as to assess the practicability of using noise barrier photovoltaics (NBPV) [21].

2. The purpose of the research
The article gives the rationale behind integrating solar panels into the design of acoustic barriers in order to ensure the investment appeal of highway projects due to the potential profit gained from using solar power.

3. The objects and the methods of research
The assessment has been aimed at the efficiency of using acoustic barrier placed along a highway to lower the noise level at a reference point (RP) located at a building-adjacent area as well as at the energy indicators of using solar panels as a part of design in acoustics barriers. The necessary set of parameters has been taken into account, e.g. the width of the highway, the distance from the highway to the residential areas, the dimensions of the barrier, the total area of the solar panels, the tilt angle of the hood in relation to the ground level [22]. The parameter values are indicative of the efficiency of the suggested solution. We have carried out a search on scientific articles and official information from the relevant agencies on the energy consumption in St. Petersburg, on the potential of using solar power at the territory of St. Petersburg and Leningrad region, solar panels (noise barrier photovoltaics (NBPV), building-integrated photovoltaics (BIPV)), as well as laws and regulations handling the issues of noise protection. In the course of the research, we have analysed the literature covering the assessment of the efficiency of acoustic barriers and using solar energy, practices 'SP 276.1325800.2016 Buildings and territories. The rules of designing the protection against traffic noise', 'ODM 218.2.013-2011 Guidelines on protection of the territories adjacent to automobile highways against traffic noise'. After applying the method of direct measurements, we have estimated how much the limit value of noise levels was exceeded at two reference points at the adjacent
territories. Thus, the necessity to implement noise protection has been justified. In order to measure the distance values needed to simulate the noise protection solutions and carry out the corresponding calculations, we used a cartography service. We have analysed the corresponding solutions involving the use of solar panels in highway infrastructure and identified the relevant shortcomings through the methods of abstraction and modelling. The configuration involving solar panels placed at the angle directed 'from the road up' decreases the height of acoustic shadow, which contradicts the main goal of the project. Placing the panels on the surface of the ground creates the danger of vandalism, which can decrease the efficiency of power generation. Using the method of indirect measurement, we have estimated the acoustic effect on noise reduction after having the project implemented, as well as power generation and associated practical indicators. In order to develop the concept of building acoustic protection in St. Petersburg, we have chosen the section of Suzdalsky prospect located along the block between houses number 89 and 93 bldg. 1. The necessity of implementing noise protection is justified in this case by the fact that the territories are located near a large highway and no acoustic barriers are currently installed at the highway. There is a sports ground and a playground between the houses and the highway, these areas are classified as residential, so the maximum acceptable noise level there is 45 dBA according to the regulations. The first stage of the study was to measure the noise level at the sports ground and the playground. To carry out the measurements, we used a professional digital sound level meter DT-805 of IEC651 standard, second degree accuracy, also ANSI S1.4 standard, second degree accuracy with a 1.5 dBA instrument error. The noise levels at the territories of the playground and sports ground were 63.5 dBA and 65 dBA correspondingly, which exceeds the maximum limit value. The measurements were carried out in the weather conditions conforming with the operation conditions of the instrument, at no precipitation, the speed of wind being 1 m/s, the temperature being 10°C, and the pressure being 740 mm Hg. The data on the relative position of the highway and the adjacent territories were obtained with a cartography service, the height of the house corresponds to that of a typical nine-storied apartment building. The distance between the front part of the house and the closest edge of the road is 74 m, the width of the carriageway is 27 m, the height of the house is 30 m. We have made a decision to reduce the noise at the reference point located at the playground using an acoustic barrier. The design of the acoustic barrier makes it possible to attach a hood carrying solar panels. The height of the vertical supports of the acoustic barrier was chosen to be 5 meters so that the tilted hood wouldn't impede the passage of heavy duty truck vehicles along the first lane and also in order to hamper possible acts of vandalism, for example, creation of street graffiti, which should be avoided since graffiti drawn on solar panels lowers the power generation capacity of said panels. To select the tilt angle of the hood carrying the solar panels, we have studied the sunshine intensity and the perspectives of using solar energy at the territory of St. Petersburg and Leningrad region. In the period from October to March, the total sunshine duration in St. Petersburg amounts to 5-6 hours per month, which would limit the power generation by the solar cells, but in the period from April to September, the number of sunshine hours is sufficient to generate the amount of energy comparable to the general levels of power consumption. The highest, most efficient rates of solar power generation at the territory of St. Petersburg can be achieved at 30° and 40° tilt angle of the panels in relation to the horizon [23]. For the project aimed at ensuring high indicators both at power generation and acoustic efficiency, we have chosen the 40° angle. A 3D-model of a highway section equipped with an acoustic barrier and solar cells placed on the hood has been developed (fig. 1).
To realise noise protection, the support of the structure must be solid and cross-sectionally wide, since it carries the weight of the entire structure, which increases in winter period due to the snow mantle accumulated at the hood of the barrier. The support plays the key role in protecting the adjacent territories from the noise, therefore, it is advised to be made of concrete. In order to make the structure more rigid, central and lateral rows of supporting pillars are placed in the middle of the road and at edge furthest from the house, which will also create additional natural ventilation under the suggested structure. In case of an accident, this design involving rows of separate pillars facilitates the organisation of the necessary evacuation of injured people and damaged vehicles, in contrast to, for instance, tunnels, where traffic is easily congested. The roof-hood is suggested to be completely covered with solar cells. To make sure the project is efficient, assessment of the following indicators has been carried out:

- reduction of acoustic load for adjacent territories,
- power generation,
- number of families who would be able to consume the generated energy,
- number of full charging cycles of electric vehicles.

In order to estimate the efficiency of the protective barrier, we have used Rosavtodor's guidelines for galleries and tunnels on the protection of territories adjacent to automobile highways against the traffic noise. The guidelines provide that in case a noise protection gallery covers 75% of the road, the noise reduction amounts to 30 dBA. Since the suggested structure covers 100% of the road, the noise reduction effect is to exceed 30 dBA. If the barrier is present, the noise of the moving traffic spreads in four directions: straight to the point, from which the source of the noise is visible over the top of the barrier; in the direction of the observation point (diffraction path) over the edge of the barrier into the acoustic shadow zone; into the shadow zone, going right through the barrier; in the direction it takes after being deflected from the surface of the barrier [24]. The method of estimating the contribution of the barrier into altering the level of noise is based on the phenomenon of diffraction, so it is necessary to know the difference between the lengths of the sound ray travelpaths to the reference point. A spot at the playground was chosen as a reference point (RP).

The difference in sound ray lengths is calculated using the following formula:

$$\delta = a + b - c = 59.12 + 18.61 - 68.75 = 8.98m$$

where $\delta$ is the difference between the lengths of the sound ray travelpaths, m; $a$ is the shortest distance between the acoustic centre of the traffic flow and the top edge of the barrier, m; $b$ is the
shortest distance from the top edge to the reference point, m; e is the shortest distance from the acoustic centre of the traffic flow to the reference point, m.

The noise reduction made by the barrier is determined using the following formula:

\[ \Delta L_{\text{barr}} = 20 \log \left( \frac{2\pi \delta}{\eta} \right) = 21.3 \text{dBA} \]  

where \( \Delta L_{\text{barr}} \) is noise reduction, dBA; \( \delta \) is the difference between the lengths of the sound ray travelpaths, m; \( \lambda \) is the length of the sound wave, m;

In order to calculate the energy generated by solar panels, it is accepted that the length of the structure along the prospect is approximately 700 metres, the width of the hood is 18 metres, then the area \( S \) of the roof-hood is amounted to 12,600 square metres.

The total intake of solar energy per one square metre in the period from April to September is 793.1 kW·h/m² at 40° tilt angle in relation to the ground and if oriented to southeast [25]. With cells having the energy conversion efficiency of 19.75%, the quantity of generated energy equals \( E_S = 793.1 \times 0.1975 = 156.6 \text{ kW·h/m²} \).

Thus, the amount of electric power generated by the solar cells integrated in the structure over the chosen period will total to:

\[ E = S \cdot E_S = 12600 \times 156.6 = 197316 \text{ kWh} \]  

where \( E \) is the total amount of energy generated by the solar panels, kW·h; \( S \) is the area of the hood, m²; \( E_S \) is the amount of energy generated per one square metre, kW·h/m².

In order to determine the number of families who would be able to use the energy, we did the calculations taking into account the electricity tariffs set for three-room apartments with gas supply housing 4 residents. For such families the standard consumption rate is 55 kW·h a month per person, accordingly, the total consumption per one family is 220 kW·h. Therefore, within six months, the generated amount of energy can be used by:

\[ N = \frac{E}{FM} = 1.500 \text{ families} \]

where \( N \) is the number of families; \( E \) is the amount of energy generated by the proposed structure over chosen period of time, kW·h; \( F \) is the energy consumption per one family, kW·h; \( M \) is the number of months.

As a result, the operation of the proposed structure ensures noise protection and solar-based power generation.

4. Conclusion

The relevance of the study is justified by insufficient state of knowledge on BIPV, NBPV and practical projects in Russian academic literature, along with the growing unprotectedness of residential areas from the noise loads. Globally, the market of solar energy integrated into architectural objects is evidently expanding, along with large-scale projects to build solar-powered noise protection facilities being realised. Since in the Russian Federation the solar power industry is only in its formative stage, developments aimed at creating solar-powered acoustic barriers will facilitate the progress in this area and might be used as a basepoint to expand the research in this field.

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