APPLICATION OF ADAPTED ACOUSTIC MODELS FOR SUSTAINABLE URBAN DEVELOPMENT PURPOSES

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Abstract. The steady increase of noise levels in human settlements degrades the quality of life of people, threatens the normal development of ecosystems and causes significant damage to the economy. This is a concern for the population and for specialists and creates objective prerequisites for carrying out studies and research for environmentally friendly solutions in support of sustainable urban development. The aim of this paper is to present an innovative method for adapting standard acoustic methods for laboratory measurements of the noise-insulation properties of vegetation. The methodology is tested by investigating the sound-shielding properties of the vegetation screens by measuring the sound insulation from airborne noise by a mass of vegetation, collected from common species, used by urban planners and landscape designers – silver leaf lime, ivy, thuja, and spruce. The results are presented in tables and graphs in frequency dependencies in frequency bands and show clearly that vegetation has good sound insulation properties and can be used as a reliable element of achieving sustainable development and enhancing the quality of life in highly anthropogenic urban environments.

Keywords: sustainable urban development, noise attenuation, acoustic camera methods, vegetative screens.

1. INTRODUCTION

It is inevitable that the greatest part of the human population globally lives in urban areas and this trend is expected to have a constant increase up to 68% by 2050 [1]. Degradation of the environment and quality of life is most feasible in cities where climate change with extreme temperature gradients and pollution presents one of the greatest challenges to society [2], [3]. Climate change has a significant impact on people, biodiversity and ecosystem functioning through threatening current habitat conditions due to heat

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and water stress [4]. Influences of climate change on society include health-related effects and socio-economic impacts induced by increased numbers of heat waves, droughts and flooding events [5]. In addition to climate change, urbanization and the associated increases in the number and size of cities have a corresponding impact on ecosystems, as urbanization leads to a significant conversion of rural to urban landscapes.

Noise is one of the biggest environmental pollutants in cities. Noise is characterized by a sound with a complex inharmonic waveform (chaotically collected tones), whose frequency and intensity are not in definite and constant proportions. In terms of quality of life, psychophysics – noise is characterized as a sound that can be qualified as irritating, stressful, frightening, generally unpleasant, and in pathophysiological it is any acoustic signal that with its strength or duration causes temporary or permanent changes in the body – disturbances in sleep, feelings of restlessness, irritability, depression, deterioration of performance and communication, reactions of the autonomic nervous system. According to construction specialists, even moderate loud noise levels of 50 to 75 dB impede communication and strain the psyche (Table 1, moderated according to [6].

Table 1. Impact of noise on human health [6]

Noise level, dB	Influence of people	
0–10	Border line for noise perception	Does not affect health.
10–30	Very quiet noise	Does not affect health.
30–50	Quiet noise	Has little effect on human health.
50–75	Moderately loud noise	It makes communication difficult, burdens the psyche.
75–100	Very loud noise	Inability to communicate, affects the hearing aid.
100–120	Unpleasantly loud noise	Damages the hearing aid, causes mental disorder, damages a number of other organs.
120–150	Painfully loud noise	Hearing loss.

In the city of Sofia, there is an attempt to introduce good practices for environmentally friendly solutions against noise in the city of Sofia [7]. The project presented the pilot constructions on a small scale made by a mixture of wood, industrial textile type “Fibran” and stones with a potential for planting vegetation. However, the project does not take into account the existing knowledge of well-proven practices for noise attenuation by vegetation [8] and would be of great importance such studies to be combined.

2. NOISE CHARACTERISTICS, SOURCES, AND MEASURES AGAINST NOISE IN URBAN AREAS

Environmental noise caused by transport is one of the main environmental problems in cities. The analysis shows the persistence of an unfavorable acoustic situation in the urban environment, with noise pollution from vehicles accounting for about 80–85% of the total noise that is realized.

The difference of the atmospheric pressure changes during the spread of noise compared to the balance. Standard reference of sound pressure level which is 0.0002 N/m^2 compared to the logarithm according to 10 base level is called a bel (B). A unit of sound evaluation in which medium and high frequencies to which the human ear is the most sensitive is dB, which is 1/10 portion of a bel (B). The unit dB often used in reducing or controlling noise, is also related to the subjective evaluation of the height of noise produced by various sources [9]. According to the most general classification, environmental noise sources are categorized into two groups as inside and outside the construction. The noise inside buildings is determined as speaking, noise of steps and of household items, while the outside noises are determined as transportation, industry, construction noise, noise generated by human activities, and noise related to entertainment, commerce and biodiversity.

The factors contributing to the increase in noise levels are mainly the poor condition and poorly organized road infrastructure, inefficient traffic organization, as well as a number of weaknesses in urban planning and the lack of noise barriers. Reducing noise pollution can be achieved through various measures: 1 – limiting speed and traffic, 2 – bypassing routes, 3 – renewing the composition, 4 – increasing the distance between noise sources and objects, 5 – implemented noise barriers.

The sources of outside environmental noise are classified as road vehicles, air vehicles, industrial roads and construction machinery. The sources forming the noise are generally classified into three groups as: i) noise arising from industry; ii) city/settlement noise and iii) traffic/transportation noise.

The level of noise is increasing or decreasing within the context of some factors. The effect and efficiency area varies in relation to geographical – location, climatic and environmental conditions. The traffic from the highways is the reason for noise pollution in most cities. It is already recognized [9] that the majority of highway traffic consists of automobiles, lorries and buses and the noise levels produced depend on the rate of their speed and power. There are other factors like location, slope and the cover of the roads that affect the noise.

3. ENVIRONMENTAL SOLUTIONS FOR SUSTAINABLE DEVELOPMENT. NOISE PROTECTION PROPERTIES BY VEGETATION

Modern urban lifestyle is associated with chronic stress, insufficient physical activity and exposure of the environment to anthropogenic hazards. On one hand, urban green space, such as parks, playgrounds, and residential greenery can promote mental and physical health and reduce morbidity and mortality in urban residents by providing psychological relaxation and stress alleviation, stimulating social cohesion, supporting physical activity. On the other hand, urban green space can reduce exposure to air pollutants, noise and excessive heat. There are many reasons to invest in urban green infrastructure technologies such as green roofs and walls, although public and private sector motivations can differ. The public sector tends to favor investment that benefits public sector challenges, such as the Urban Heat Island Effect, urban microclimate issues, storm, water and rainwater management, air quality, ground and air traffic noise, fine particulate air pollution, recreation and community activities, social cohesion, health and biodiversity issues.

Sustainable urban development requires the search for environmentally friendly techniques. and reducing noise levels. Finding environmentally friendly solutions is an interdisciplinary problem, the solution of which is the task of physicists, acousticians and engineers as well as urban planners and landscape architects. This paper discusses vegetated screens as one possible solution to cougar mitigation, as urbanized lifestyles and practices increasingly prove conclusively that vegetation is a natural and necessary attribute of the urban environment. Sustainable development of Green infrastructure (GI) is often referred to as air quality improvements, local temperature regulation, or increased energy savings provided by green roofs, urban parks or street trees [2]. GI can also improve the health and well-being of urban residents by facilitating psychological relaxation and stress relief, providing enhanced opportunities for physical activity and reducing exposure to noise, air pollution and excessive heat. In regard to noise attenuation, there are various barriers are being used to reduce or prevent the noise. The wall structure is the most dominant part of the structural element. The material to be used in noise barrier walls may be materials like precast concrete, metal, wood, brick and stone. The quality and character of the wall is directly related to the material used and the texture created. While wood is generally used in rural areas and the suburbs; materials like concrete, stone and metal are preferred in urban areas.

4. DATA AND METHODS

The research methodology identified was part of the doctoral study of the author [8] which had not been published widely. Because of the rising interest in improving the quality of life in the period of COVID-19 pandemic it is introduced now. Here an innovative method for adapting the standard acoustic methods, particularly developed for the measurement of noise attenuation of vegetation in the controlled conditions environment of an acoustic camera is presented. The proposed methodology aims to prove one of part of the multifunctional benefits of integrating high-quality green infrastructure as part of adapting cities to climate change. The sustainable development requires more nature-based solutions and the creation of a healthy outdoor environment in cities. The research objects identified, are part of the infrastructure in the capital city of Sofia.

The research work has been separated into the following stages; Stage A – Field observation and determination of the suitable vegetative species that had been used in Urban Green infrastructure in Sofia and with great importance for urban planning; Stage B – Development of the methodology and implementation of measurements in the controlled situation of the acoustic camera; Stage C – Research analyses and recommendations.

5. ACOUSTIC CHAMBER MEASUREMENT METHODOLOGY

To determine the effectiveness of green screens for noise protection purposes, a standardized method of measuring airborne noise insulation using two reverberation chambers was used, analogous to building acoustics. The chambers were built in accordance with international standards and were additionally equipped for the needs of the experiment on the determination of sound insulation and sound absorption of a volume of plant mass – leaves and branches of various ornamental tree species. The passage of noise through the test element is ensured without transmission-by-side bypasses. The reception chamber of the airborne sound insulation – low-level chamber is made with double enclosure structures, box-in-box type. The volume of the low-level chamber is 119 m^3 and that of the high-level chamber is 170 m^3. The two chambers are connected by an opening in which the research element is installed. The opening has dimensions of 2.67 m/4.25 m. The chamber doors are double wooden. The location of the specimen to be measured between the low-level chamber and the high-level chamber is shown in Fig. 1. The measurements were carried out with acoustic equipment manufactured by Bruel & Kaer – Denmark.

Fig. 1. Photo 1. View of the test hole between High-level acoustic camera and Low-level acoustic camera (author)

The methodology for both experiments consists of successive measurements of the average sound pressure levels at the measuring points and subsequent laboratory determination of the difference, with the calculation of the sound absorption coefficient as an indicator of sound insulation. The measurements shall be carried out in all terzoctave bands with geometric mean frequencies from 100 to 3150 Hz. The requirements that the noise source was located in the high-level room at least 2 m from the test specimen and that the measuring microphone was located at a height of 1.5 m from the floor of the room shall be met. The microphone was placed alternately in the high- and low-level rooms at 6 measurement points covering evenly the entire surface of the test sample. The sound absorption coefficient and the difference in sound pressure levels created by plant barriers (leaves and branches) of the following plant species – silverleaf lime (Tilia argentea Desf.), ivy (Hedera helix L.) thuja (Thuja occidentalis L.), common spruce (Picea abies Karst.) and columnar juniper (Juniperus communis f. hibernika) had been e determined. The last species was studied as a natural barrier of container plants, transported and placed in the sound insulation test hole, with preserved root system and natural habitat.

The volume of plant mass tested in the two types of experiments, to determine sound insulation and sound absorption, was attached to a net stretched over 12 wooden frames. The plant mass was collected from the surface part of the crown of the species under study and included fractions of small branches and offshoots with their leaves (Fig. 2) A prerequisite for the measurement of sound insulation from airborne noise is the tight fit of the test specimen to the edges of the opening and the uniform distribution of sound pressure over the specimen surface.

Fig. 2. Photo 2. Modeling vegetative sample, lime (Tilia argentea Desf.) (author)

The larger dimensions of the test specimens allow unwanted edge effects to be neglected. Attachment is performed in a manner simulating the natural position of the crown. Each of the frames is of modular size 1/1.5 m, chosen to satisfy both the requirements of the standard and the possibility of manipulating and moving the shielding specimens for both experiments. Thus, a test area of 9 m^2 in the reverberation chamber was provided. The vegetated aperture between the CBN and the CNH has a total area of 4.5 m^2 which ensures the necessary accuracy of the acoustic measurements. Three options were investigated, as follows: single screen with dimensions 1.5/3.0/0.10 m; double screen with dimensions 1.5/3.0/0.25 m; double screen with an air gap of 0.20 m between the two screens, dimensions 1.5/3.0/0.40 m. The bags for collection of the samples were weighed to the nearest 0.01 kg. The examined samples from each frame were separated into fractions – leaves and branches, in this case, thin branches and small branches and weighed again. In order to achieve uniform screen density when laying the plant mass, the requirement that the mass of each frame should not differ from the others by more than 0.5

kg was observed. This condition was checked again when the specimens were removed. The degree of sound level reduction behind the vegetation screen, measured in an acoustic chamber for airborne noise isolation measurements, was reported by the differences in sound levels in the high-pressure chamber (HPC) (i.e. in front of the vegetation screen) and in the low-pressure chamber (LPC), (behind the screen).

6. RESULTS AND ANALYSES

The analysis of the results was carried out by tracking the different options for the arrangement of the frames and for the different plant species, respectively, as follows. The plots (Figs. 3, 4, 5) of the difference in noise levels for all species in the three variants, clearly highlight the trends of screen behavior depending on the species composition of the foliage studied and the screen design.

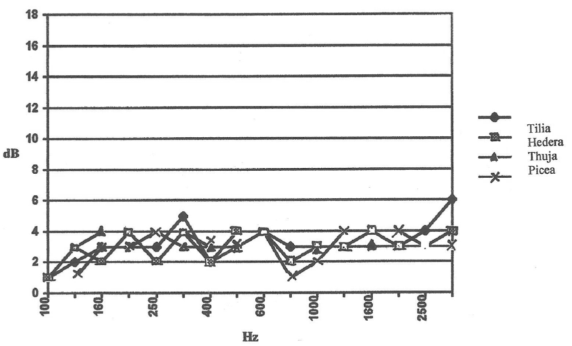

Fig. 3. Noise insulation level from single screen

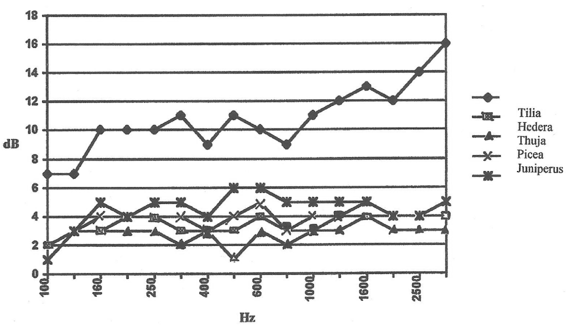

Fig. 4. Noise insulation level from the double screen

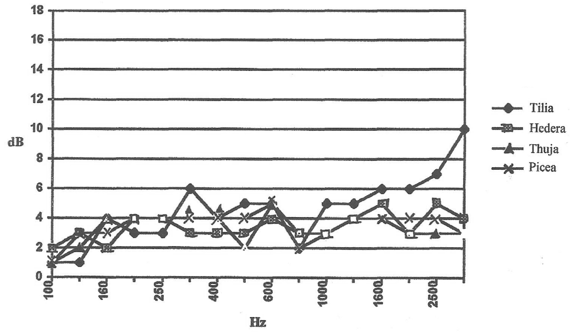

Fig. 5. Noise insulation level from double screen with a gap of 0.20 m between the two screens

Single noise barrier with the green mass on them of all tested vegetative species shows similar results for sound insulation values between the low-pressure chamber and the high-pressure chamber, with a small difference in values of 1 dB. The maximum value of sound reduction is at a bandwidth of low frequency 315 Hz and applies to Linden, 5 dB, and the lowest value applies to thuja, 3 dB respectively. All the frequency curves for the single screen have two pronounced maxima of attenuation at the low-frequency bands 160–315 Hz and at the high-frequency bands – above 2000 Hz, respectively. The attenuation values are in the range of 1 to 5 dB. These two maxima are not as pronounced in ivy.

The second variant of the vegetative screens studied, two screens with no air gap between the two screens, experiments cases with increasing screen density. The densification of the plant mass is identified by a change in the corresponding biometric indices. First of all, one of the main factors, screen mass increases and this leads to an increase in some of the other metrics, such as surface density and volume per unit vegetative biomass. The densification is the cause of the weaker relative optical transmittance. Secondly, the air volume in which the vegetation is located increases, leading to a decrease in the bulk weight and fill factor relative to the unit screen. In the case of double-layered screens, the clear superiority in the degree of sound insulation of lime (Tilia argentea Desf.) over the other four species is apparent. The sound reduction values of the lime screen are in the range from 7 to 16 dB. The results for the other species – thuja, spruce, ivy, and columnar sumac have similar reduction values, which are in the range of 3–4 dB. That is, linden has twice the sound insulation capacity in comparison with spruce, thuja, ivy, and columnar sumac. In this case, thuja has the weakest sound insulation performance, with a reduction of 3–4 dB. The average figures apply to ivy and spruce – 4–5 dB noise reduction, respectively.

In the third option, comparing the results of all species tested shows again the best performance for Linden, but with a smaller difference between the values of Linden and the other three species. This fact is explained by the reduced density of the vegetation compared to the volume in which it is located compared to the two-layer screen without an air gap. The maximum value for the linden is 16 dB for the high frequencies – 3150 Hz and the results for the other frequencies hover around this value over almost the entire measurement range. The ivy baffle showed the weakest performance, with a 3 < dB maximum noise level reduction, respectively. It is concluded that silver-leaf lime shows the best sound insulation performance for all tested variants.

Fig. 6. Photo 3. Noise protection screen by variety of tree species, including Tilia argentea, Desf. blvd Universiada, Sofia (author)

In addition to noise attenuation, as it was seen from the photos, there are other valuable benefits from natural vegetation (Fig. 6 and Fig. 7). The two vegetative screens presented were chosen from the real situation of urban planning in the capital city of Sofia as a good planning practice when the edge was designed in harmony with the nature and surrounding residential or park area. Such as the trees are planted as close as possible to each other, the space behind the barrier provides shelter, keeps the residential areas cool during summer heat waves and provides a nice environment for walk and relax. These health benefits depend on the overall greenness of residential areas and can be provided by adequate urban planning mechanisms.

Fig. 7. Photo 4. Noise protection screen by mixture of vegetation including Tilia argentea Desf., BjalaCherkva str., Sofia (author)

7. CONCLUSIONS

The modelling measurements carried out in the controlled situation of an acoustic camera proved that vegetative screens have real noise insulation properties. In the case of double-layered screens, the clear superiority in the degree of sound insulation of lime (Tilia argentea Desf.) over the other four vegetative species investigated. The sound reduction values of the lime screen are in the range from 7 to 16 dB, which in a quite substantial decrease of noise levels. The results for the other species – thuja, spruce, ivy, and columnar sumac have similar reduction values, which are in the range of 3–4 dB. Thus, linden (Tilia argentea Desf.) shows promising twice bigger sound insulation capacity in comparison with the other species – spruce (Picea abies Kast.), thuja (Thuja occidentalis L.), ivy (Hedera helix L.) and juniper (Juniperus communis f. hibernica). All the frequency curves for the single screen have two pronounced maxima of attenuation at the low-frequency bands 160–315 Hz and at the high-frequency bands – above 2000 Hz, respectively. Thus through the innovative modelling methodology for noise measurements in acoustic camera, it was proved that green screens have very good insulation characteristics and can be widely used for noise protection in urban areas.

The data presented, must be considered as valuable support for further application of ecological solutions against noise and negative environmental conditions in the capital city of Sofia because urban lifestyles and practices are increasingly proving conclusively that vegetation is a natural and necessary attribute of the urban environment.

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