Plants Role in Noise Reduction of Interior Walls (Comparison of Noise Absorption in Native Species and Non-Native Species)

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Abstract

Noise pollution is one of the most important features of architectural spaces having a great impact on the comfort of residents. Therefore, providing appropriate and sustainable solutions for noise pollution control is essential. Today, with the use of man-made synthetic materials, it has been tried to improve the sound performance of buildings. The purpose of this study is to show the characteristics of plants for noise absorption and noise reduction and to find suitable species to use in interior walls of buildings to reduce noise pollution between the two adjacent spaces. Library studies were first used to identify plants and their morphology in order to identify plant species with these characteristics. Adaptability of acoustic principles to plant tissue was also assessed, and then the species morphological parameters were extracted through laboratory calculations and measurements using scales, calipers and AutoCAD software. The results showed that *Nephrolepis Exaltata* (Boston ferns) has more sound absorption. As a result, the sound absorption can be improved by the use of covered walls. It can also be assumed that non-native species present in Iran exhibit better sound absorption than native species.

Keywords: Acoustics, Noise reduction, Plants, Ferns, Interior space.

1. Introduction

The inner space and its location are the most important factors in a house. Although a house is a closed three-dimension space, a correct designing can make a good connection with the outer area and provide peace and comfort for the residents (Akbari, 2020: 37-45). Noise pollution is one of the most important environmental pollutants that endanger human health in different aspects. The physiological and psychological effects of sound on humans often appear gradually and in the long run, they have a direct effect on the human nervous system and its negative consequences (Fallah, 2006: 41-50). This is especially important in high-traffic urban spaces. For this reason, it is necessary to provide appropriate and sustainable solutions for noise pollution control. Today, noise has become a global problem, and polls in many countries show that noise is one of the main reasons for the decline of people's quality of life. The residential environment is an area that is subject to major problems, especially noise pollution (Alamdari, 2008: 1-10). The emergence of residential spaces near highways and high-traffic urban areas is currently affecting the comfort of residents. Also, in residential and indoors complexes, noise is transmitted through adjacent units that is annoying for residents. In educational and office spaces, sound exchange between two classes or two rooms is a problem. As a result, sound or noise exchange must be minimized to create better productivity of spaces.

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1.1. Theoretical Foundations

In this section, the principles of acoustics as well as the sound absorption in plants will be studied, to select a suitable approach by adapting the acoustic principles and the morphology of plants.

A. Sound and Noise

The major acoustic issues in a building can be either controlling the noise or unwanted sound in the desired space or providing the interior acoustic conditions in one space for the appropriate purpose. The best and easiest way to differentiate between sound and noise is the difference between feeling and subjectivity that determines that which sound is desirable and which is undesirable. For example, human speech is wanted in an apartment, but the same sound is unwanted and is considered annoying if heard in the adjoining room (Stein, 2015).

The sound emitted from the source hits the room's borders or another large level. The sound intensity is reduced before reaching this level, in accordance with the law of squared distance and the absorption by air. Air absorption only occurs in large rooms at frequencies above 2000 Hz. When sound waves hit the wall (Fig 1), some parts of the reflection are absorbed and some parts of it are transmitted to adjacent spaces. This transmitted energy has little effect on reducing the sound intensity produced and is important in adjacent spaces (Stein, 2015).

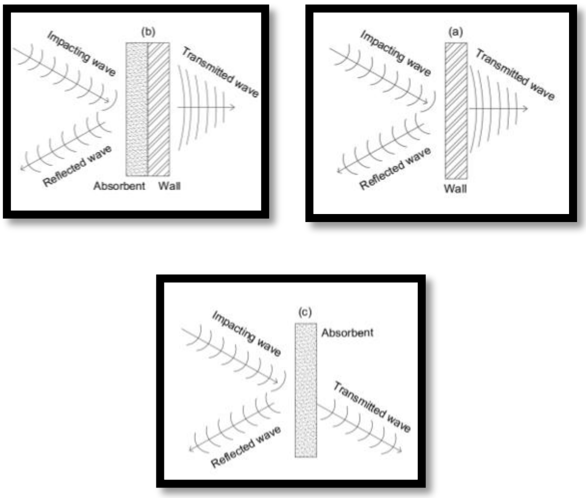


Fig. 1. a) When a sound wave hits a heavy barrier, most of the energy is reflected, some of it is absorbed and slightly passes through the barrier. b) When the adsorbent is mounted on a heavy wall, it traps the sound and prevents reflection and the wall mass reduces the passage. c) If the barrier of the adsorbent is used alone, very little energy is reflected, some of it is absorbed, and most of it passes (Stein, 2015).

a) Transmission Loss (TL) and Noise Reduction (NR)

The Transmission Loss is a barrier of the ratio of acoustic energy transmitted from the barrier to the acoustic energy descending on it, in dB. This number is used to determine the sound quality of a wall and to obtain it under laboratory conditions (In Europe, Transmission Loss is called, R.). This number is important for building designers, this noise reduction defines the difference between the intensity levels in two rooms (Stein, 2015), that means:

$$NR = IL_1 - IL_2 \quad (1)$$

In addition its relation with the Transmission Loss inhibition is as follows:

$$NR = TL - 10 \log \frac{S}{A_R} \quad (2)$$

b) Types of absorbents

The absorbents (Table 1) are now being investigated:

Table 1
Classification of absorbents (Retrieved from (Stein, 2015))

Absorbents	Factors affecting sound absorption	Features
Fibrous (porous) materials	Thickness, density, porosity, strength of the material	1) At high frequencies the absorption is higher than the low frequencies. 2) Absorption rate does not always depend on thickness, but it depends on the type of material and method of installation as well. 3) When using porous absorbers in block cavities, the absorption coefficient increases at high frequencies. 4) The periodic return of most of these materials is very long and non-recyclable.
Panel resonator	Thin laminated board or linoleum facing the sealed space containing air.	1) Low frequency absorption. 2) Use in recording studios.
Volume resonator	It usually contains air that is enclosed in bulky areas and connected to the outside by a narrow duct.	1) To be used at a specific frequency. 2) Concrete blocks can be used as resonators.

c) Properties of absorbents

The following table examines the properties of several sound absorbers (Table 2):

Table 2
Characteristics of the types of absorbents

Absorbent substance	Features
Acoustic Tile	Fire resistance, Installation methods: In-grid, Nailing on thin board, Pasting, Tile materials: Mineral fibers with NRC 0.45 to 0.75, Glass fibers coated with NRC 0.95, Used in high humidity.
Perforated cladding tile	Commonly used on false ceilings, mineral wool or glass wool fillers, cladding of different colors, applicable to all spaces, brightness reflection, fire resistance.
Acoustic panels	Made of inorganic cement-treated wood fiber, false ceiling, mounted by nails or glue, high structural strength, relevant flame spread, sports panel wall and school corridor, NRC 0.4 to 0.7, moisture resistant.
Plaster Acoustic	Plaster-based material that incorporates lightweight or fibrous aggregates. Used in bends and non-planar surfaces, 1 to 1.5 inches thickness, fire resistance, moisture resistant, lower absorption than acoustic tiles.
Sound barriers	Baffles and suspended panels, prominent appearance.
Wall panels	Having layers made out of wood or metal, mineral fibers (NRC = 0.5) or glass fibers (NRC = 1.5) and fabric coating, flame retardant fabric coating, used in work desks, conference room and educational spaces.
Sound absorbent resonator	Large scale.
Carpets and curtains	Absorption on mid and high frequency.

Source: (Retrieved from (Stein, 2015)

Human activities always cause serious and irreparable damage to the environment. Experts in environmental research generally believe that there is no single, unique factor causing pollution to a part or the whole environment. In addition, the consequences and dilemmas of environmental pollution vary widely under different conditions. Environmental pollution is caused by any physical or chemical product caused by human activity that can pose a threat to human health, natural and climatic ecosystems at regional or global levels. Building and its related industries are recognized as one of the high consumption and polluting industries in the world, and construction is said to be the largest after agriculture, industry in the world (Ghaem maghami, 2013: 135-146). Cities are responsible for 70% of global CO2 emissions, resulting from the use of resources such as fuels, minerals and metals, as well as food, soil, water, air, biomass and ecosystems, Therefore the buildings sector is key for low-cost climate mitigation worldwide (Arabi, 2020: 77-91). According to some studies, most sound insulators are non-recyclable and environmentally destructive while being made.

B. Absorption of Sound in Plants

Applying greenery in buildings is being consolidated as an interesting way to improve the quality of life in urban environments. Among the benefits that are associated with greenery systems for buildings, such as energy savings, biodiversity support, and storm-water control, there is also noise attenuation. Despite the fact that green walls are one of the most promising building greenery systems, few studies on their sound insulation potential have been conducted. In addition, there are different types of green walls; therefore, available data for this purpose are not only sparse but also scattered. The main results were a weighted sound reduction index (Rw) of 15 dB and a weighted sound absorption coefficient (α) of 0.40. It could be concluded that green walls have significant potential as a sound insulation tool for buildings but that some design adjustments should be performed, such as improving the efficiency of sealing the joints between the modular pieces (Azkorra, 2015: 46-56). Therefore, the results prove that green walls are effective in reducing noise pollution, But the question is, what parameters are effective in this sound reduction. In this research, plants will be studied to identify sound reduction factors in plants and according to these factors, it will be tried to increase the efficiency of green walls.

The vibration of sound waves is absorbed by the leaves and branches of trees. Factors such as flexible porous walls are effective in absorbing sound. The foliage of the trees absorbs sound due to its flexibility, softness and smoothness, and the trunk of the tree and the heavy branches cause the sound to deviate. For this reason, trees influence the absorption of unpleasant sounds with the above characteristics. The thickness of the trees, the leathery feature of the leaves, and the bending quality of the branches allow the annoying sounds to be absorbed. Trees are also efficient in scattering and cracking the sound. Even grasses can absorb the sound. In the meantime, broadleaf trees have better effects than coniferous trees due to their large foliage area. This holds true, as long as the leaves are not autumnal and permanent, it is believed that the effects of acorns on autumn are much greater. If the ground is covered with grass, broken waves hit the ground, absorbing significant amounts of broken sounds (Erfani, 2008).

The anatomical structure of all woods is composed of cellular cavities that trigger the activity of the cambium ring during the years of tree growth. Such a special structure causes the sound to enter the cell cavities after being hit by the surface of the wood, partially absorbed by the cell wall over time and the remainder into the next cavity. As a result, the absorption, refraction, and successive reflections of the acoustic wave decrease its intensity. Low-density wood is a better insulator for absorbing sound at higher frequencies (Bokour, 2006). Oak, plantain, Tehran pine and acacia have shown better sound absorption than other trees (Dabiri, 2000)

One of the methods of pollution control is the use of green walls in building facades. The noise reduction index is 15 dB using these walls. It can be concluded that these walls are a potential factor in sound absorption (Azkorra, 2015: 46-56). Vegetation reduces acoustic emission by three main mechanisms:

1. Ground effect, caused by the destructive interference of soil waves, at frequencies below 500 Hz.
2. The second mechanism is due to the reflection and scattering of plant factors (trunks, branches, sprigs, leaves). When a dense vegetation layer is placed between the source and receivers, due to reflection and scattering, especially at medium and high frequencies, it results in a loss of sound pressure.
3. The foliage can absorb a significant amount of acoustic energy (50% of random sound waves) depending on the morphological parameters. When the sound hits the plants, vibration occurs in its elements, causing a disturbance by converting acoustic energy into heat. In addition, the absorption of sound is boosted by the energy loss caused by thermo-viscosity friction at the boundary layer at high frequencies (Alessandro, 2015: 913-923).

1.1. Literature Review

Early studies on the acoustic properties of the plants were based on the acoustic effect of tree belt. Aylor (1972) (Aylor, 1972: 197-205) analyzed the transmission of sound through dense corn in the green belts of pines and dense grasses. He deduced early prediction models of sound attenuation. He particularly observed that leaf surface density increases noise attenuation, especially at higher frequencies; whereas the effect of the earth (the interference between the direct waves and the reflected waves from the earth) is dominant in the frequency range of 200 to 1000 Hz. In another paper, he showed that sound attenuation increases with increasing leaf area density, leaf width and frequency.

Martens (1981) (Martens, 1981: 303-306), investigated the vibration of four different plant leaves using a Laser Doppler vibrometer. Measurements showed that the leaves were able to convert a small amount of acoustic energy to heat by vibration. Martens' research shows that a single leaf is capable of absorbing acoustic energy, especially at high frequencies.

In the Hosanna project, Smyrnova (2010) (Smyrnova, 2010: 1-12) studied the acoustic behavior of evergreen shrubs and ground and bushy shrubs. The results of the break time between the frequencies of 250 to 1600 Hz showed that: At frequencies below 500 Hz, the pressure drop is due to soil uptake, while for frequencies between 500 and 1600 Hz, the loss of sound is due to vegetation uptake. In this study, it was also shown that soil (soil thickness, water content, soil type and the amount of porosity) is an effective element in sound absorption (Alessandro, 2015: 913-923).

Horoshenkov (2012) (Horoshenkov, 2012: 1-8) introduced a relatively simple method for determining the sound absorption by a plant (Fig 2). He used a vertical impedance tube to determine the sound absorption of plants in the presence or absence of soil.

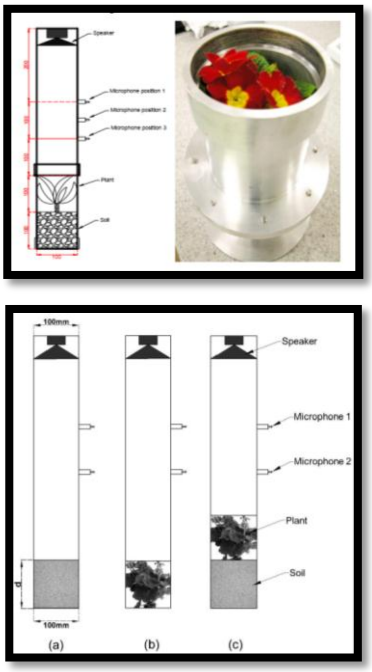


Fig. 2. Schematic drawing of impedance tube with clay, b) Single plant c) Plant on clay (Horoshenkov, 2012: 1-8)

In his other study, Experimental Evaluation and Modeling of the Sound Absorption Properties of Plants for Indoor Acoustic Applications, he found that the following items might be influencing factors in sound absorption:

Mean thickness of a single leaf (T_f), mean weight of a single leaf (w_f), mean area of a single leaf (a_f), number of leaves (n_f), equivalent plant height of the plant (h_p), equivalent volume occupied by the plant (v_p) and dominant angle of leaf orientation (θ_f) (Fig 3).

The results showed that the sound absorption in plants was mainly affected by the leaf number, density, area and leaf orientation angle. The higher the leaf surface density and the greater the dominant angle of leaf orientation, the higher the acoustic absorption coefficient values (Horoshenkov, 2013: 1-42).

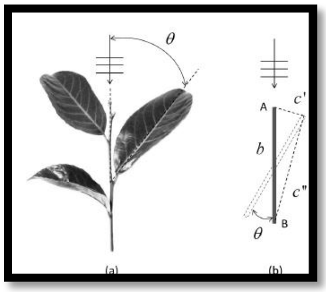


Fig. 3. Definition of dominant angle of leaf orientation (Horoshenkov, 2013: 1-42).

Asdrubali (2014) (Asdrubali, 2014: 1-9) tested five plant species *Helxine soleirolii* (baby tears), *Nephrolepis Exaltata* (Fern), *Begonia Rex* (Begonia), *Adiantum capillus-veneris* (Maidenhair Fern) and *Hedera helix* (Green Ivy) in the presence of a 10 cm layer of porous soil made of perlite (30%) and coconut fibers (70%) has set. The purpose of this study was to investigate the feasibility of providing absorbent panels of live plants as an alternative to man-made acoustics to improve the interior sound quality.

Unlike many other works, this paper examines the use of green systems for acoustic treatment of indoor spaces. These systems are believed to potentially replace human-made and even sustainable acoustic absorbers due to their aesthetic effects and good regeneration. It is generally believed that green plants are not good absorbers, but research has shown that vegetation levels can absorb up to 50% of the noise.

In this study, ferns and *Helxine soleirolii* showed the highest amount of sound absorption. A rectangular frame made of wood (12.5 x 106 x 106 cm) was made to fit the sample. Examples are as follows:

1. Soil and *Helxine soleirolii* were exposed to different vegetation types. (25, 50 and 90 species mounted on the frame)
1. Soil and *Nephrolepis Exaltata* were exposed to different types of vegetation. (25, 50 and 90 species mounted on the frame)
2. Soil and 45 *Helxine soleirolii* and 45 *Nephrolepis Exaltata* were placed on the frame (Fig 4).

Fig. 4. Planting at different densities (Asdrubali, 2014: 1-9)

The results confirmed that the soil is the main absorber; however, the foliage significantly contributes to absorption (Fig 5), that is, in the configuration with the 90 specimens installed (more plants and more density). The results showed that the highest absorption was at 800-1600 Hz. *Helxine soleirolii* increase acoustic absorption by 11%. The combination of 45 *Helxine soleirolii* and 45 ferns increases the absorption rate to 12%. The highest absorption share is for ferns, which increase the absorption of acoustic energy by 25%. The *Nephrolepis Exaltata* sample is capable of absorbing 98% of acoustic energy at frequencies close to 1600 Hz. In addition, *Helxine soleirolii* show good sound absorption and can absorb sound up to 90%.

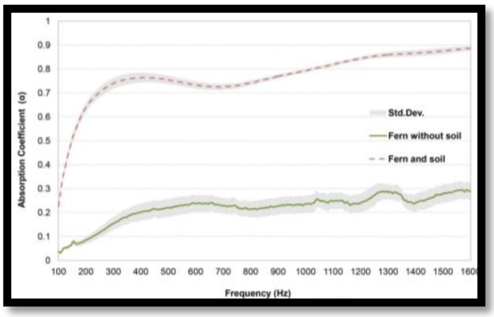


Fig. 5. Comparison of fern sound absorption with presence and absence of soil (Alessandro, 2015: 913-923)

Alessandro (2015) (Alessandro, 2015: 913-923) investigated the characteristics and sound absorption of two types of *Nephrolepis Exaltata* and *Helxine soleirolii* in the inner walls at 50 to 1600 Hz. The purpose of this research is to find a way to replace man-made acoustic absorbers. The presence of plants increases the absorption of sound throughout the frequency range studied. Ferns and soil substrates increase absorption coefficient by 0.75 at a frequency of 300 Hz. It reduced to 700 Hz and reaches 0.9 at 1600 Hz.

Making absorbents by vegetation in addition to aesthetic reasons, improve air quality and psychological factors. According to a similar experiment conducted at the workplace on 51 workers in the presence and absence of plants showed that symptoms of discomfort in the presence of plants decreased by 23% and cough and fatigue decreased by 30 and 37%, respectively.

Kolyaei (2016) (Kolyaei, 2016: 1-20), provided a classification of green walls.

The potential of the green wall sound insulation tool for buildings can be confirmed. The green wall showed a similar or better acoustic absorption coefficient than other common building materials, and its effects on low frequencies were of particular interest because its observed properties were better than those of some current sound absorbent materials at low frequencies. In the study by Azkorra (2015), that the voice frequency was around 60 dB and this corresponded to the frequency at which this modular green facade is more efficient for absorbing sound, so it could be used very effectively in public places for instance restaurants, hotels, and halfway up the street to the passage of people (Azkorra, 2015: 46-56). As can be observed in Figure 6 the capacity of the green wall to reduce airborne noise, which is expressed by the R coefficient, was lower than the other constructive solutions. These values, although lower than those for other common constructive solutions, are promising and could be enhanced with some simple improvements to increase the mass of this constructive system and efficiently seal the joints between the modular pieces.

Generally, various vertical greenery system fall into two broad categories such as “support” and “carrier” (Table 3). The support systems are designed to guide plants up on the vertical surface, while carrier systems are designed to contain the media for planting on the vertical surface. The selection of systems is guided by the type of plants to be planted. The support systems, also commonly termed as “green facades”, allow climbing plants and cascading groundcovers to grow up the facade on specially designed support structures. In contrast, carrier systems are able to host a greater diversify of plants, including groundcovers, shrubs, ferns, grasses, sedges and even mosses. Such systems are commonly termed “living wall” (Table 1) (Jaafar, 2011, 1-9).

Today, the concept of a green wall or vertical garden is a set of 30 x 30 boxes and in case of damage, the relevant box can be removed and the plants can be easily replaced. These boxes are in the shape of a rectangular cube with dimensions of 30*30*10 cm and are made of polycarbonate – polypropylene; in their upper part, a groove is installed in which water pipes are placed (Azhdanian, 2017: 6-9).

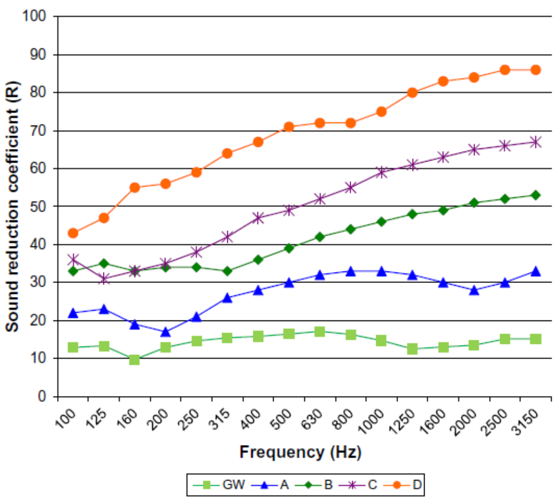
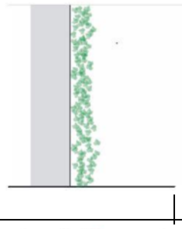
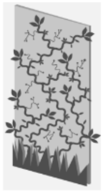
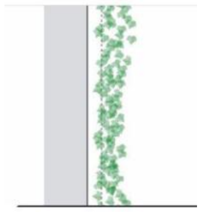
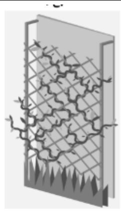
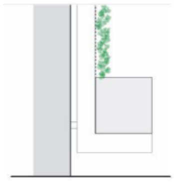
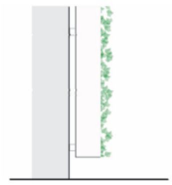
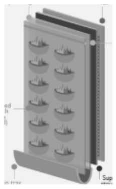
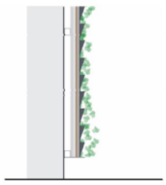
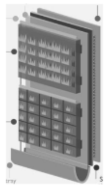


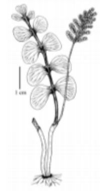
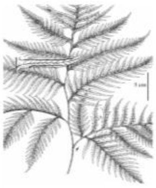
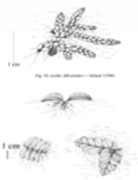
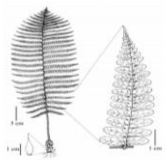
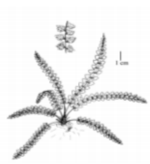
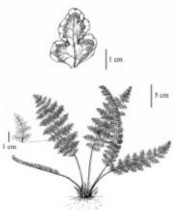
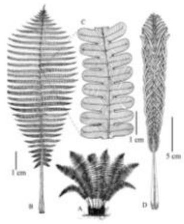
Fig. 6. Sound reduction coefficient (R) comparison between the green wall (GW) and common constructive solutions:
A. Thermal double-glazing, B. Brick, C. Lightweight aggregate block 215 mm thick with plaster finish in both sides, D. Two leaves of 12.5 mm + 19 mm plasterboard on metal studs (Azkorra, 2015: 46-56).

Table 3
Green Wall Types

Green Wall Types	Figure	Green Wall Types	Figure
Support (Direct)	 	Carrier (Indirect)	 
Indirectly mixed with planters		Living wall is based on planters	
Living wall is based on a layer of felt	 	Living wall based on the modular system	 

Source: (Retrieved (Kolyaei, 2016: 1-20)

Table 4
Ferns and fern allies of Iran.

 Marsilea quadrifolia	 Osmunda regalis	 Equisetum ramosissmum	 Botrychium lunaria
 Pteris denata subsp	 Adiantum capillus-veneris	 Pteridium aqulinum	 Salvinia natans
 Thelypteris palustris	 Dryopteris affinis	 Asplenium viride-Runcmark	 Asplenium adiantum-nigrum
 Cheilanthes acrostica	 Woodsia alpina	 Blechnam spicant	 Matteuccia struthiopteris

Source: (Retrieved (Akhani, 2009: 1-141)).

1.1 Ferns and fern allies of iran

The Caspian forests provide suitable habitats for the growth of many ferns and fern allies in Iran. In semi-arid and mountainous areas of Iran, mesophilous plants are restricted to rock crevices, waterfall proximity, stream banks and lakeshores. Based on field collections and study of herbarium specimens in Iranian herbaria, an updated and annotated inventory of the Iranian ferns and fern allies is provided with an identification key, original line-drawings and/or photographs of most species, and distribution maps. Altogether 52 species (Table 4) are known in 26 genera and 15 families, viz (Akhani, 2009: 1-141).
Ophioglossaceae, Psilotaceae, Equisetaceae, Osmundaceae, Marsileaceae, Salviniaceae, Dennstaedtiaceae, Pteridaceae, Aspleniaceae, Thelypteridaceae, Woodsiaceae, Blechnaceae, Onocleaceae, Dryopteridaceae and Polypodiaceae.

2. Research Methods

The goal of this project is to find a way to absorb sound. In the first step, according to the studies of plant tissue mechanics, it is found that the plants have a sound absorption capacity. As a result, library studies are first carried out to identify plants and their morphology. The second part of the research includes the factors affecting the sound absorption and its identification. At this stage, the acoustic principles can be adjusted to the plant tissue. In the third step, the morphological characteristics of the fern plant and its effective parameters in sound absorption are investigated by computational and laboratory methods (using scales, calipers and AutoCAD software). Finally, in the fourth stage of the research, the parameters measured are determined by logical reasoning of the plant that has better sound absorption and Transmission Loss.

2.1. Research steps

Studies have shown that ferns have a better sound absorption than other plants. In this study, four types of ferns (two non-native and two native species in Iran) were selected (Fig 7).
Then the effective parameters in sound absorption i.e.: Mean thickness of a single leaf (T_f), mean weight of a single leaf (w_f), mean area of a single leaf (a_f), number of leaves (n_f), equivalent plant height of the plant (h_p), equivalent volume occupied by the plant (v_p) and dominant angle of leaf orientation (θ_f), were measured.

Fig. 7. The ferns studied: Polystichum SP, Nephrolepis Exaltata, Nephrolepis Exaltata 'Norwoodii'

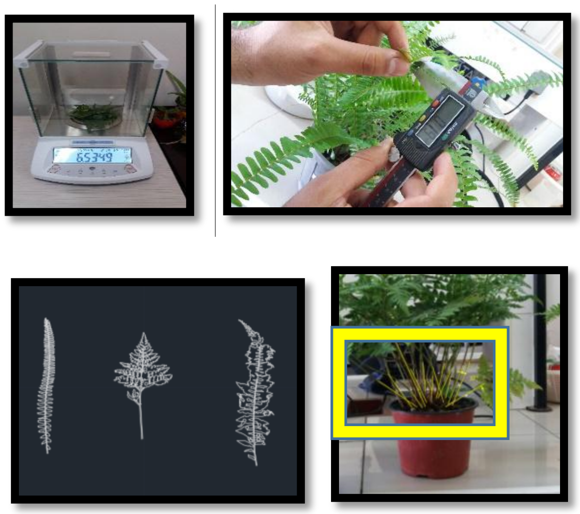


Fig. 8. Leaf weight calculation, Leaf thickness calculation, Leaf area calculation, Leaf angle measurement

Scales were used to measure weight and calipers were used to measure thickness (Fig 8).

To obtain the dominant leaf area and orientation angle, the shape of the leaf was plotted using AutoCAD software and the area was obtained. Direct measurements cannot infer the equivalent volume occupied by the plant (V_p) and leaf area density (A_v). For this purpose, the following relation can be obtained (Horoshenkov, 2013: 1-42):

$$v_p = a_p . h_p \quad (3)$$

$$A_v = \frac{(n_f . a_f)}{v_p} \quad (4)$$

In this respect, a_p is the area under cultivation: $a_p = \pi . d^2/4$ and d is the pot diameter (Table 5).

Table 5
Measuring morphological parameter of the plant

Plant species	Leaf area a_f (m^2)	Leaf thickness T_f (mm)	Number of plant n_f	Leaf weight w_f (g)	Dominant angle of leaves orientation θ_f (deg)	Height of plant h_p (m)	Equivalent volume occupied by plant V_p (m^3)	Cultivation surface a_p (m^2)	Leaf area density A_v (m^{-1})
Pteridium aquilinum	0.050	0.14	3	10.00	10	0.45	0.0040	0.009	37.50
Polystichum SP	0.007	0.21	32	5.10	31	0.33	0.0029	0.009	76.13
Nephrolepis Exaltata	0.004	0.16	46	1.46	21	0.40	0.0036	0.009	47.27
Nephrolepis Exaltata 'Norwoodii'	0.011	0.17	15	4.57	18	0.40	0.0036	0.009	45.00

3. Results and Discussion

The results of previous studies showed that sound absorption in plants was mainly affected by leaf number, leaf density and area and leaf orientation angle. In addition, according to the results of the Horoshenkov research, it was found that *Nephrolepis Exaltata* with a 10 cm layer of porous soil made of perlite (30%) and coconut fibers (70%) showed higher sound absorption. New research also confirms results similar to Horoshenkov. According to the results of the table 5, native ferns (*Polystichum SP*) with high leaf area, higher leaf density and higher plant angles are more suitable for sound absorption and *Nephrolepis Exaltata* (non-native ferns) are in second place. However, according to the topic discussed on sound absorption and with logical reasoning method and acoustic principle findings, the gap that the air passes through, will also let the air make its own way; native ferns have longer stems than non-native ferns (Fig 9) and there is a gap between the soil surface and leaves. As a result, non-native ferns that have more convex stems and their leaf growth starts from the lower level are better for sound absorption. It can be concluded, therefore, that the *Nephrolepis Exaltata* is better for sound absorption. In addition, depending on the characteristics of the ferns plant, a variety of planting boxes and living walls can be used for planting.

Fig. 9. Long stems of native species compared to non-native

4. Conclusion

Noise pollution is one of the factors affecting human well-being and their living space. It has been tried to find a way to control the noise pollution with different materials such as glass wool, rock wool, foam types, acoustic tiles etc. Most of these materials are factors causing environmental degradation and are not recyclable. Plants with their sound absorbing characteristics can have a significant effect on the rate of sound absorption. In this study, two samples of native ferns and two samples of non-native ferns were investigated. Based on the results of the experiment, it was found that non-native *Nephrolepis Exaltata* are suitable for planting in the inner wall to control noise pollution. In this study, it can be reasonably hypothesized that species with leaves far from the soil and long stems have better sound absorption than the species that are close to the soil surface. The vertical green wall is a costly system and its maintenance costs are high. However, it offers several benefits apart from acoustic behavior, such as improving the air quality by absorption of pollution and dust as well as reducing the greenhouse effect by CO_2 absorption, increasing Oxygen, increasing property values, reduction of cooling loads through better insulation, and psychiatric effects. The main results were a weighted sound reduction index (R_w) of 15 dB and a weighted sound absorption coefficient (α) of 0.40 (given that the voice frequency was around 60 dB). It could be concluded that green walls have significant potential as a sound insulation tool for buildings; but some design adjustments should be performed, such as improving the efficiency of sealing the joints between the modular pieces. Generally, various vertical greenery system fall into two broad categories: "support" and "carrier". The support systems are designed to guide plants grow up on the vertical surface, while carrier systems are designed to contain the media for planting on the vertical surface. Based on the morphology of ferns and acoustic factors, the soil and plant surface should be the same throughout the wall. For this purpose, use the carrier method such as living wall based on planters and the modular system seems appropriate.

It is expected that the future researches design acoustic absorbers by modeling the morphological and sound absorbing characteristics of plants, which are more sustainable environmentally with better sound absorption.

References

1) Akbari, P., Yazdanfar, A., Hosseini, B., Norouzian, S. (2020) '*Identification of Building Façade Functions by Using Fuzzy TOPSIS Technique'*, , Space Ontology International Journal, 9 (1), 37-45
2) Akhani, H., Khoshravesh, R., Eskandari, M., Greuter, W. (2009) '*Ferns and Fern Allies of Iran'*, Rostaniha, 10 (35), 1-141.
3) Alessandro, F., Asdrubali, F., Mencarelli, N. (2015) '*Experimental Evaluation and Modelling of the Sound Absorption Properties of Plants for Indoor Acoustic applications'*, Building and Environment, 94 (2), 913-923.
4) Alamdari, Z., Khavanin, A., Kokabi, M. (2008) '*Manufacturing Sound Absorber Based on Combined Recycling of Polyethylene Trephetalat and Polystyrene at Low and Median Frequencies'*, Audiology, 17 (1), 1-10.
5) Arabi, S., Golabchi, M., Darabpour, M. (2020) '*A Qualitative Approach Towards the Implementation of Urban Sustainability in Tehran*', Space Ontology International Journal, 9 (1), 77-91.
6) Asdrubali, F., Horoshenkov, K., Mencarelli, N., D'Alessandro, F. (2014) '*Sound Absorption Properties of Tropical Plants for Indoor Applications'*, The 21st International Congress on Sound and Vibration, China, 1-9.
7) Aylor D. (1972) '*Noise Reduction by Vegetation and Ground'*, J.Acoust.Soc.Am, 51, 197-205.
8) Azkorra, Z., Perez, G., Coma, J., Cabeza, L., Bures, S., Alvaro, J., Erkoreka, A., Urrestarazu, M. (2015) '*Evaluation on Green Walls as a Passive Insulation System for Buildings'*, Applied Acoustics, 89, 46-56.
9) Azhdanian, L. (2017) '*Green wall, a combination of architecture, technology and nature',* Javaneh, 6-9.

10) Bokour, V. (2006) *Acoustic of Wood*, Translated by Ali Yavari, Islamic Azad University. Iran: Tehran.
11) Dabiri. M. (2000) *Environmental Pollution: Air- Water- Soil- Sound*. Etehad, Iran: Tehran.
12) Erfani, M. (2008) '*Noise Pollution and its Control Methods with Emphasis on Green Space Design'*, Department of Environmental Protection of North Khorasan, Khorasan.
13) Fallah, P., Oveisi, E., Esmaeli, A., Ghasempori, M. (2006) '*The Effect of Traffic Noise Pollution on Public and Mental Health of Yazd Citizens'*, Enviromental Studies, 43, 41-50.
14) Ghaem maghami, P., Rahayi, O. (2013) '*Environment and Sustainable Measures in the Design of Future Buildings',* Enviromental Science and Technology, 2, 135-146.
15) Horoshenkov, K., Yang, H., Benkreira, H., Kang, J. (2012) '*Acoustical Properties of Living Plants'*, Proceedings of the Institute of Acoustics, 1-8.
16) Horoshenkov, K., Benkreira, H. (2013) '*Acoustic Properties of Low Growing Plants*', Acoustical Society of America, 133, 5, 1-42.
17) Jaafar, B., Said, I., Rasidi, M. (2011) '*Evaluating the Impact of Vertical Greenery System on Cooling Effect on High Rise Buildings and Surroundings: A Review'*, Senvar 2011, 1-9.
18) Kolyaei, M., Hamzenejhad, M., Bahrami, P., Litkouhi, S. (2016) '*Comparison of Different Types of Green Wall to Achieve Sustainability',* Modern Research in Civil Engineering, Architectural & Urban Development, Turkey, 1-20.
19) Martens, M., Michelsen, A. (1981) '*Absoprtion of Acoustic Energy by Plant Leaves'*, J.Acoust.Soc.Am, 1, 303-306.
20) Stein, B., Reynolds, J. (2015) *Acoustic Principles in Buildings*, Translated by Parvin Nasiri, Ministry of Road, Housing & Urban Development. Iran: Tehran.
21) Smyrnova, Y., Kang, J., Cheal, C., Tijs, E., Bree, H. (2010) '*Laboratory Test of Sound Absorption of Vegetation*', Proceedings of the 1st EAA-EuroRegio, Slovenia, *1-12*.