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Evaluating the Consequences of Noise Pollution for the Health of Residents in the Apartments based on Electroencephalography*

Maryam Haghayegh[a]- Hadi Keshmiri[b]- Khosro Movahed[c]- Malihe Taghipour[d]**

[a] Ph.D Candidate of Architecture, Faculty of Art and Architecture, Shiraz Branch, Islamic Azad University, Shiraz, Iran.

[b] Associate Professor of Architecture, Faculty of Art and Architecture, Shiraz Branch, Islamic Azad University, Shiraz, Iran (Corresponding Author).

[c] Associate Professor of Architecture, Faculty of Art and Architecture, Shiraz Branch, Islamic Azad University, Shiraz, Iran.

[d] Assistant Profesoor of Architecture, Faculty of Art and Architecture, Shiraz Branch, Islamic Azad University, Shiraz, Iran.

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ABSTRACT

The increasing population, the increase in pollution, and the following environmental issues have made fundamental problems for human beings' quality of life and biological health. Noise pollution as one of the above-mentioned issues can have dangerous auditory and non-auditory effects on human health. The acoustic comfort in the residential space affects the residents' health directly and indirectly at the three levels of physical, mental, and social health. Therefore, the current study aims to recognize and evaluate the effective architectural components in acoustic comfort in the apartments of Shiraz City as well as the adverse effects of environmental noise pollution and its consequences on the residents' health in the living rooms of an apartment complex through electroencephalography. It is a qualitative-quantitative study and the data is collected and analyzed through a researcher-made questionnaire and brain imaging. To do so, the brain waves of samples are recorded using an EMOTIV EPOC 14-channel EEG headset and after recording the EEG signals, the obtained data are analyzed by the NeuroGuide Software, and the brain activity oscillations of the samples were compared to normal database. The results obtained from the current study indicate that outdoor noise pollution is the first distorting factor of acoustic comfort with the three sub-components of the source, propagation path, and noise-receiving location. Also, the results indicate that if the background noise level increases from 40 (Iranian National Building Code for Living Room) to 53dB, it would lead to a change in concentration, attentional bias and distortion in the emotional and cognitive organization of the individuals. Therefore, noise control in the initial phases of planning, ideation, and design can reduce the above-mentioned problems to some extent.

Keywords: Noise Pollution, Residential Architecture, Health, Brain Waves.

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** E_mail: keshmirihadi@yahoo.com

1. INTRODUCTION

Today, the population growth all over the world, industrialization of the cities, and increase in pollution have caused many environmental problems. Studies have shown that inattention to environmental conditions inflicts serious damage to human quality of life and biological, mental, and social health (Shakerinia 2010). Although human beings spend a significant portion of their life in the built environment, they are not much aware of such environments' impacts on their health (Tabatabaei and Tamanayi 2013). Based on the definition provided by the WHO, health is a "state of complete physical, mental and social well-being and not merely the absence of disease and infirmity" (Rahimi 2010). Thus, health consists of three "physical", "mental", and "social" dimensions, and any damage or defects in each of these three axes distort the individual's equilibrium and as a result, endanger his/her well-being (Hakimian 2012). Adverse effects of unwanted sounds for mental health include mental fatigue, stress and anxiety, anger, violence, lack of concentration, academic failure, reduced labor productivity, etc. The effects of unwanted sounds on human physical health include: nervous sensitivity, extreme excitability, fatigue, dizziness, headache, and migraine, as well as loss of body balance, adrenaline hormone secretion, weak eyesight, weak sexual power, the disorder in body metabolism and digestive system, gastritis and gastric ulcer, indigestion, decrease in skin resistance response, shortness of breath, changes in electroencephalography activity, blood vessel contraction, increased blood pressure and intravascular pressure, and temporary and even permanent deafness (Korte et al. 2001). Social health includes the positive dimensions of the mind in creating appropriate social relationships with fellow human beings. These dimensions consist of a set of social norms such as environmental mastery, self-acceptance, positive relationships with others, being purposeful in life, personal growth, and independence (Rafiei et al. 2019). Noise pollution can also affect these dimensions from different perspectives.

Therefore, considering the variety of consequences of noise pollution as a problem, it seems that comprehensive knowledge and awareness of this harmful environmental component and its consequences, whether in the field of public awareness or among design professionals, can moderate these problems and improve the health quality to some extent. Therefore, aiming to recognize and evaluate the consequences of noise pollution for health, the present study firstly identifies and assesses the architectural components that affect acoustic comfort in apartment buildings in Shiraz city, and then evaluates the changes in the behavior of the brain against noise pollution, as the empirical part of the research, using a wearable electroencephalography device (Emotiv).

2. RESEARCH BACKGROUND

Concerning noise pollution and its adverse effects in architectural spaces, much research has been done so far. To better examine these studies, they can be evaluated in three general categories. The first category, while referring to the consequences of noise pollution, examines the architectural considerations and acoustic design. Ghafari et al., while pointing out the adverse effects of noise pollution, dealt with noise pollution reduction techniques through acoustic design in residential buildings. The results showed that by designing and using appropriate materials and the use of double-glazed walls and windows, it is possible to create sound insulation against airborne sounds such as traffic noise. Regarding the implemented samples, the modification of the walls will improve the transmission loss (Ghaffari, Ghaffari, and Saleh 2013). Hammer et al. suggest sustainable building design and energy management and environmental design, the use of sound-absorbing coatings to limit sound in the propagation circuit, new building materials, and location and design considerations (Hammer, Swinburn, and Neitzel 2014).

The second category examined the adverse effects of noise pollution on the residents' health in residential buildings. Saremi and Rezapour divided these adverse effects into two auditory and non-auditory categories. Non-auditory effects lead to three types of changes, including biological, mental, and behavioral changes in the individual (Saremi and Rezapour 2013). Farooqi et al. also expressed the non-auditory effects of noise to be depression, dizziness, headache, high blood pressure, physiological stress, and insomnia (Farooqi, Iftikhar, and Nukshab 2021). Stansfeld et al. showed that exposure to noise affects cognitive functions including central processing and language comprehension (Stansfeld and Matheson 2003). Nazeen et al. analyzed the causal relationship between noise and mental complaints with focus on psychological symptoms (Nazeen and Sardar 2020).

Dzhambov et al. showed that exposure to noise pollution is indirectly related to residents' mental health (Dzhambov et al. 2018). Leijssen et al. investigated the relationship between traffic noise and residents' depression and showed that exposure to noise above 70 decibels is significantly correlated with depression (Leijssen et al., 2019). Akinnubi particularly evaluated the causes and sources of noise pollution to analyze the health challenges and measures to achieve a healthy environment through correct positioning of residential places and noise-producing locations (Akinnubi 2020). Regarding positioning, in a novel study, Elida et al. presented health-risk maps to residents of Japanese cities, indicating the number of health risks when they are exposed to noise on a local and regional scale (Elida, Tagusari, and Matsui 2021).

The third category dealt with the use of new techniques, tools, and methods to analyze the effects of noise on health. Zhang et al. investigated the effect of noise pollution on lack of concentration by using a wearable electroencephalography device (Emotiv) to examine brain activity and showed that the beta and gamma powers in the left and right temporal prefrontal cortex can distinguish two focused and non-focused states, especially in T7 and AF4 channels. These indicators can be considered as an objective analysis of sustained attention and inattention of a person (Zhang et al. 2021). Ke et al. investigated the effects of different noise conditions on cognitive performance using the Emotiv device. The findings indicated a negative correlation between participants' performance and noise exposure. Internal cognitive states including attention, stress, and mental load were affected in different degrees by noise. Assessing the impact of noise on cognitive functions helps to explain the mental effects of functional impairment. In other words, neurological monitoring with electroencephalography provides a basis for predicting job performance in different noise conditions (Ke, Du, and Weilu 2021). Yong et al. evaluated the heard sound of traffic in high-rise urban residential buildings with a new subjective method based on 3D Virtual Reality (VR) with Head-Related Transfer Function (HRTF) and Head-Mounted Display (HMD). Subjects were exposed to noise pollution through virtual reality in a living room of a high-rise building. In addition, the subjects filled out a questionnaire to investigate how they respond to noise, and perceive the source of the noise and the space. The results of this research showed that the subjects' mental responses to noise in terms of loudness and the perceived noise level cause disturbance in their cognitive activity (Yong and InJo 2019).

Table 1. A Collection of Applied Research on Noise Pollution in the Architectural Space

Research Area	Authors	Research Subject	Year
Architectural Considerations and Acoustic Design	Mardomi et al.	Architectural design considerations in reducing noise pollution	1391
	Ghaffari, Ghaffari, and Saleh	Acoustic design in providing acoustic comfort in residential apartments	1393
Consequences of Noise Pollution on Residents' Health	Saremi and Rezapour	Non-auditory effects of sound exposure: biological, mental, and behavioral	1392
	Stansfeld and Matheson	Non-auditory effects on health and cognitive functions including central processing and language comprehension	2003
	Hammer, Swinburn, and Neitzel	Sound and sleep disorder, heart disease, diabetes, learning, comprehension, and concentration	2014
	Akinnubi	Different causes and sources of noise pollution, health challenges, and measures to achieve a healthy environment	2020
	Nazeen and Sardar	Noise pollution and subjective health complaints such as psychological symptoms and concentration	2020
	Farooqi, Iftikhar, and Nukshab	Depression, dizziness, headache, blood pressure, stress, insomnia	2021
	Elida,Tagusari, and Matsui	Converting noise maps into residents' health-risk maps	2021
	Leijssen et al.	Road traffic and residents' depression	2019
	Dzhambov et al.	Road traffic and public mental health	2017
The Use of New Techniques and Tools in Analyzing the Effects of Sound on Health	Ke, Du, and weilu	Internal cognitive states including attention, stress, and mental load, and the correlation between noise pollution and lack of concentration by examining brain activity in exposure to noise using the Emotiv device.	2021
	Yong and In Jo	Residents' subjective response to noise, sound source perception, and spatial perception using HMD and HRTF	2019

A review of the studies clarifies that the research on the effects of noise pollution on the space users' quality of life are extensive, however, it seems that the research that quantitatively evaluates the effects of the architectural components on acoustic comfort and its impact on health in residential architecture, and more specifically, a specific space in the building, and neuroscientifically assesses these feffects, is rare.

3. THEORETICAL FRAMEWORK

The theoretical foundations of this research can be investigated in three areas: noise pollution and housing, noise pollution and health, and noise pollution and the brain, which are briefly mentioned in the following:

3.1. Noise Pollution and Housing

In psychological discussions and qualitative terms, noise pollution is an unpleasant, undesirable, and unwanted sound. From a quantitative point of view, noise is a combination of different sounds with different intensities and wavelengths, which are unpleasant to the ear and do not have a specific composition (Oveisi et al. 2016). The most appropriate scale to obtain the average sound pressure level to determine the noise level in variable sound sources, such as the sound caused by traffic, which changes with time, is the "Level equivalent noise (Leq) " per "decibels" (Abbaspour 1992, 32). The sound standard in the Iranian residential areas is 55 dB during the day and 45 dB at night. Also, this standard in residential-commercial areas is 60 decibels" during the day and 50 decibels" at night, and in solely commercial areas, it is 65 decibels during the day and 55 decibels at night (Monavvari 2001, 53). The residential environment, as a space where a person spends most of his life, is not an exception and it is facing this harmful environmental effect. Therefore, provision of acoustic comfort requires attention and taking measures to prevent above-standard sound levels (bothering sounds) at work and in place of residence in their design.

3.2. Noise Pollution and Health

The consequences and adverse effects of noise pollution on residents do not appear directly and in the short term. Although sound does not remain in the environment for a long time and is perished shortly, this short-term duration has a significant long-term effect on humans and the surrounding environment. The psychological and physiological effects of noise on humans generally appear gradually and in the long term. It affects the nervous system and its adverse effects emerge. In a general division, the effects and consequences of noise pollution can be investigated in two areas: Auditory and non-auditory. The non-auditory effects are the result of exposure to noise as a stressful factor and have been less investigated, leading to the occurrence of three categories of changes, including biological, mental, and behavioral changes in the individual. Biological effects include sleep disorder, autonomous function (cardiovascular system, endocrine, digestive system), and immune system and growth. Mental effects include irritation, fatigue, and decreased concentration. Finally, behavioral effects include drug use, psychological symptoms, and learning disorders. Figure 1 shows the consequences of exposure to environmental noise (Saremi and Rezapour 2013).

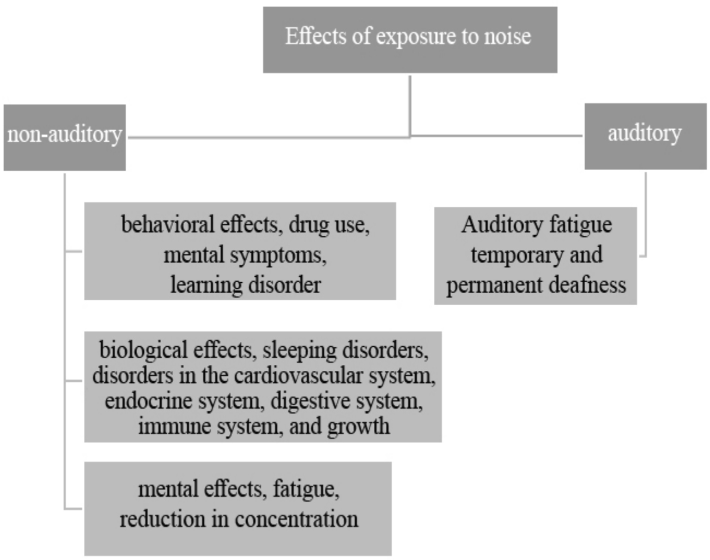


Fig. 1. Auditory and Non-auditory Consequences of Exposure to Noise
(Saremi and Rezapour 2013)

Undoubtedly, since all these consequences, whether auditory or non-auditory and ultimately, human behavior, are the result of the brain's interaction and functions, knowledge, and awareness of the mind and the complex world of the brain can have an important effect on recognizing the abilities and limitations of brain performance when exposed to noise. The human brain plays a central role in the body's nervous system. After hearing the sound of the environment and analyzing it, the brain commands all the autonomic movements of the body and even leads to the appearance of pleasant or unpleasant feelings and chemical reactions in the body. Figure 2 shows how a person receives and perceives the surrounding environment (Tahiri 2010, 14).

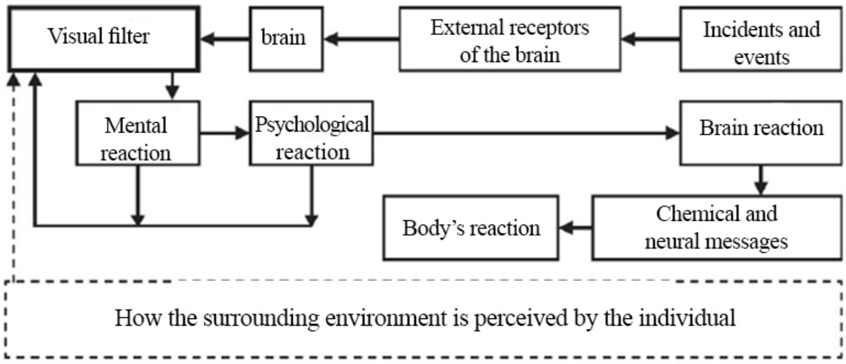


Fig. 2. How the Surrounding Environment is Perceived by the Individual
(Taheri 2010, 14)

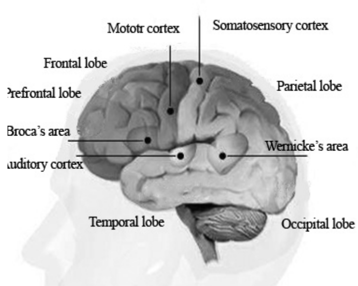
From the examination and comparison of figures 1 and 2, it can be concluded that the evaluation of the reaction of the brain as the center of the body's nervous system to environmental noise is very extensive and requires comprehensive research in all specialties. Therefore, this research only focuses on the adverse effects of noise pollution on the cognitive functions of health. Reading, problem solving, memory, motivation, and concentration are among the cognitive skills that may be affected by noise. Also, noise can have a negative effect on safety and productivity (King and Davis 2003). Noise can irritate people, change problem-solving strategies, and reduce the ability to pay attention and focus on ongoing activities. It also affects social functioning and disrupts verbal communication. A noisy environment reduces brain activity and causes inconsistency in performing physical activities, disruption in understanding content as well as conversation and learning power (Stansfel and Matheson 2003).

3.3. Noise Pollution and the Brain

Understanding the effects of noise pollution on the brain and its adverse effects on human performance when faced with a noise source is a very new category and requires the use of new techniques and tools to investigate and monitor the reaction of a person's body when exposed to noise. The human brain receives information through the senses of smell, taste, touch, sight, and hearing. Brain cells are responsible for receiving and sending messages to other neurons. Each region of the brain has a specific task. The input information is analyzed by different regions in the brain depending on their type. Table 2 shows different regions of the brain, brain activities, and the location of each activity in the brain.

Table 2. Different Areas of the Brain, Brain Activities, and Regions of each Activity in the Brain

Types of Brain Activities	Region
Sight	Occipital lobes
Hearing	Temporal lobe
Touch	Somatosensory cortex
Smell and Taste	Thalamus, olfactory bulb, prefrontal lobe
Language and Speaking	Motor cortex, hearing, Wernicke's area, Broca's area
Planning, Ideas, and Decision-making	Frontal and prefrontal lobes
Social Interactions	Prefrontal lobe
Memory	Temporal, frontal, and prefrontal lobes



(Baars and Gage 2014)

According to Table 2, each region in the brain has a specific task. Knowing these regions is very important for accurate diagnosis and analysis of the brain's reaction during activities or facing stimuli. According to the table, the "temporal lobe" is responsible for hearing. Therefore, when a person hears a sound, he sends information to the temporal lobe of the brain, and the brain neurons in this region create various reactions and feelings by receiving and processing the information. In other words, by identifying the location of the brain where the relevant processing has taken place, it is possible to determine the feeling and reaction of a person when hearing a sound, and the extent and intensity of that reaction. "Frontal lobe" and "prefrontal lobe" are the most significant areas involved in cognitive processing and procedures in the research (Bockova 2007). The regions highlighted in green on the right side of Table 2 are the those involved in the exposure to sound, which were also analyzed in this research.

Each person has five types of electrical activity (brain waves) in his cerebral cortex, which are called "gamma", "beta", and "alpha", “theta”, and “delta” in order of the shortest wavelength or the highest frequency to the highest wavelength or the lowest frequency. Each of the brain waves in a person's brain has a specific purpose and helps the person maintain the best mental performance (Baars and Gage 2014). Research evidence indicates "alpha waves" as a suitable wave for examining the amount of cognitive processing in people (Cicek and Nalcaci 2001; Chan 2008). Other studies also indicate that the oscillations of "theta waves" are related to a range of cognitive, behavioral, and emotional variables.

4. METHODOLOGY

According to the issues raised and the necessity of the discussion, the present study aimed to identify and evaluate the adverse effects of noise pollution on health in two parts. First, it identifies and evaluates the architectural components that affect acoustic comfort in apartment buildings in Shiraz city. Then, using a wearable electroencephalography device (Emotiv), it evaluates the behavior of the brain when exposed to noise pollution as an empirical part of the research.

In the first part, the components affecting acoustic comfort obtained from the research literature and theoretical framework were extracted and divided into five main components and eleven sub-components. The components and sub-components can be seen in Figure 3.

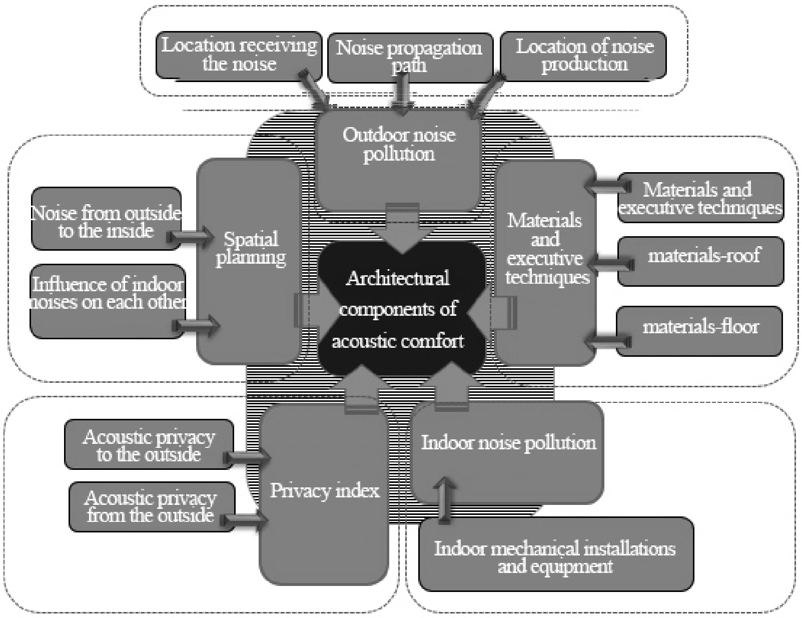


Fig. 3. Effective Components

The current study is descriptive-analytical survey that was conducted among the residents of apartment buildings with a density of 4 to 8 floors in Shiraz. Sampling was done by random cluster method. The sample size was calculated as 384 persons using Cochran's formula. The data collection instrument in this research was a researcher-made questionnaire consisting of 5 components and 11 sub-components which was formulated based on the Likert scale. Environmental components were extracted based on the conducted research (Fig. 4) and questions were formulated based on them. The face validity of the items of the measurement instrument was approved by the professors, and the reliability of the questionnaire was obtained using "Cronbach's alpha coefficient", which was calculated as 0.866. The results and statistics are expressed with the help of SPSS Ver.22 in two descriptive and inferential levels. In the second part of the research, based on the results of the first part, the effects of double-glazed windows and sound intensity level on the acoustic comfort of the residents and how the brain responds to the change in background noise intensity level were investigated. Since the living room is one of the most used spaces among the spaces of a residential unit in Iran where residents spend more time during the day, and naturally, the quality of the space and the intensity and duration of unwanted environmental sounds can have a direct effect on the health and mental comfort of the space users, 10 men in the age range of 30-40 years, who were mentally healthy and did not have any disease or drug use, were asked to have their brain waves recorded with the help of an EMOTIV EPOC 14+ device (Fig. 4-A) at 1:00 p.m. at noon, on ten consecutive days in September with an average temperature of 19.90 Celsius degrees, a humidity of 30%, and a clear and cloudless sky with a light level of 200 lux, in an apartment building (Fig. 5) which is located near one of the main streets of Shiraz city.

Fig. 4. (A): Emotive Epoc 14+ Device, (B): az 8921 Sound Meter, and (C): EEG

First, to determine the best time to record the background noise level, an az 8921 sound meter with an accuracy of ±1.5 dB was use (Fig. 4-B) in the two states of all the windows being closed and opening two windows at three different hours (Table 2).

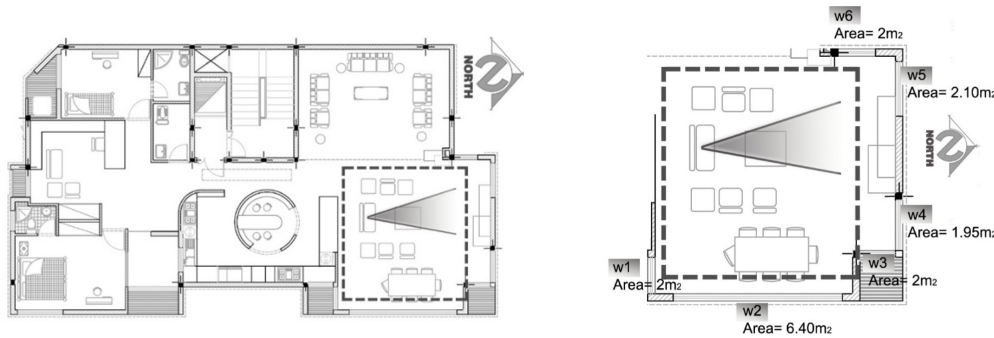


Fig. 5. (A): Plan of the Living Room of in an Apartment Building, (B): Plan of the Living Room, Number and Location of Windows

Among these three times, the sound level was more consistent with the standard table of national building regulations at 1 p.m. (Table 4), so it was chosen as the sampling time (Table 3).

Table 3. Background Noise Level at Three Different Times in the Day in the Living Room

Time	Location	The Background Noise Level When all Windows are Closed/ Decibels	The Background Noise Level When Two Windows with a Pane of 3.20 Square Meters are Open per Decibel
7 A.M.	Living Room	35	45
1 P.M.	Living Room	40	53
6 P.M.	Living Room	45	58

According to the standard of the maximum "background noise level" allowed in different spaces of the building, taken from Topic 18 of the National Building Code, the maximum allowable background noise level in the living room is 40 decibels (Table 4).

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Table 4. Maximum Allowable Background Noise Level in the Indoor Spaces

Space Type	Maximum Allowable Background Noise Level per Decibel
Bedroom and Reading Room	35
Living and Work Rooms	40
Kitchen	45
W.C. Closed Public Spaces	50

At first, the sound level of 40 dB was ensured by controlling the windows and their insulation. Then, the EMOTIV device was placed on the person's head and its electrodes were adjusted at different points of the head. As mentioned in Table 2, the human brain has different regions, each of which has a task. To record the brain waves of the sample, the brain wave recording electrodes were also placed in the different areas of the brain. According to the "International 10-20 System", these electrodes were placed on specific points of the head skin (Fig. 6-A), and according to the location, they were marked with an abbreviation: frontal cortex with the letter F, frontal lobe with the letters FP, central regions with letter C, temporal cortex with letter T, parietal lobe with letter P, and the Occipital lobe with letter O. Odd numbers indicate the points that are located in the left hemisphere of the brain and even numbers indicate points in the right hemisphere.

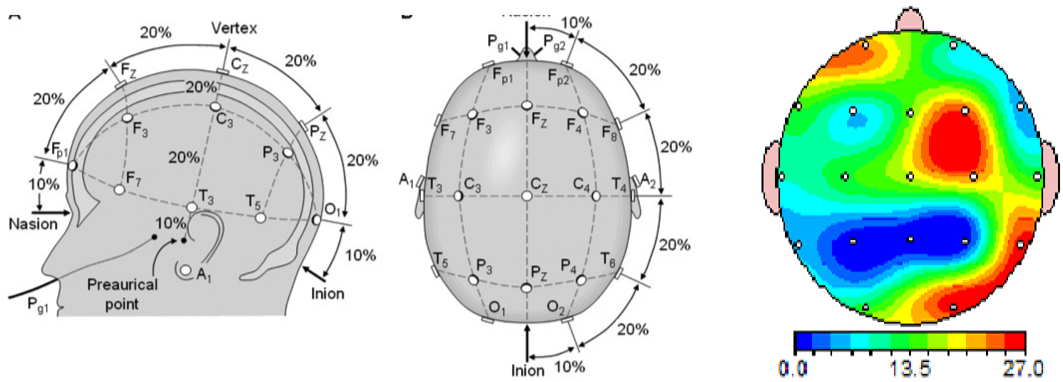


Fig. 6. (A): 10-20 Standard System to Stick the Electrode on Different Points of the Head, (B): Brain Map - waves with less Intensity of Activity are Marked with Blue Spectrum and Waves with more Intensity with Yellow, Orange, and Red

After ensuring that all the electrodes are in their place on the subject's head in the points of Figure 6-A, he was asked to rest for three minutes in the living space (Fig. 5-B). After three minutes, two panes of window W2 with an area of 3.20 square meters were opened and the background noise level increased to 53 dB. The person's brain waves were recorded again in the new state (Fig. 4-C). After recording the EEG signals, the obtained information is converted into a number by MATLAB software and entered into the NeuroGuide software and the normal brain map database software, and the oscillations of the person's brain activity are compared to the normal database. The results are displayed in the form of brain maps with colored heads (Fig. 6-B). By comparing the measurements obtained from the brain waves of each person with the normal values in the database, it is determined which wave and in which area has an inappropriate activity. Waves with less intensity of activity are characterized by a blue color spectrum and waves with higher intensity of activity are characterized by yellow, orange, and red colors. Brain function can be examined and studied by analyzing these maps and comparing them with reference and normal patterns (Demos 2005).

5. FINDINGS AND DISCUSSION

The findings of the first part of the research on the evaluation of the architectural components affecting acoustic comfort in apartment are presented in Table 5. According to the results of Table 5, using the Friedman test, the weighting and ranking of the architectural components affecting acoustic comfort show that the significance level of the components is equal to 0.000 at the 95% significance level. In this table, a lower rank and a higher mean indicate acoustic discomfort.

Table 5. Weighting and Ranking of the Architectural Indices and Parameters of Residents' Acoustic Comfort

	Component	Rank	Mean rank	Degree of Freedom	Chi-Square	Significance Level
Architectural Parameters and Indices of Residents' Acoustic Comfort	Outdoor Noise Pollution	1	4.99	4	1460.131	0.000
	Spatial Planning	2	3.90			
	Effective Privacy Index	3	2.69			
	Materials and Executive Techniques	4	2.41			
	Indoor Noise Pollution	5	1			

According to Figure 7, it seems that among the architectural components that affect the acoustic comfort of the residents, outdoor noise pollution is the most effective, while indoor noise pollution is the least effective in the distortion of the acoustic comfort of the residents.

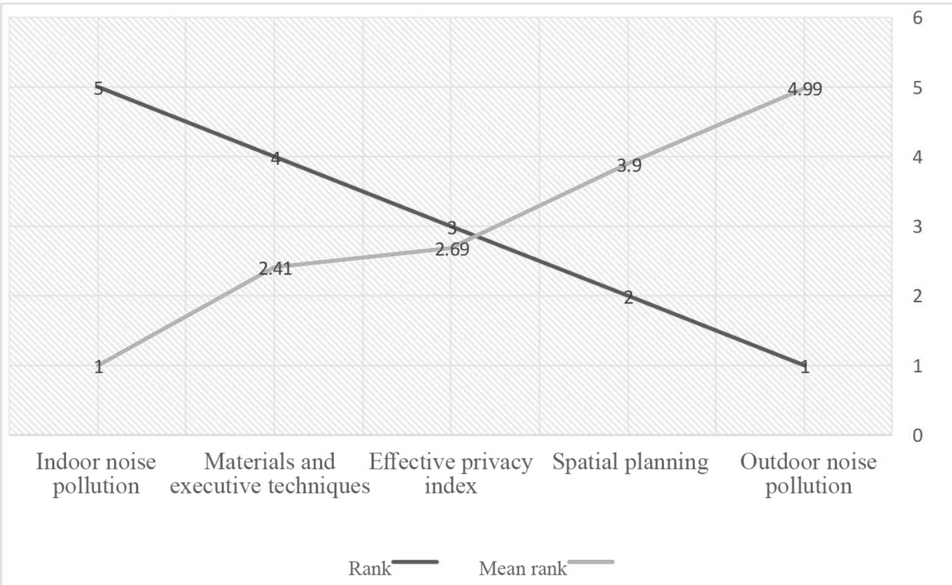


Fig. 7. Weighting and Ranking of the Architectural Indices and Parameters of Residents' Acoustic

Also, according to the results of Table 6, using the Friedman test, the weighting, and ranking of the architectural components of the acoustic comfort of the residents show that the significance level of the components is equal to 0.000 which means that they are significant at the 95% level. A lower rank and a higher mean indicate acoustic discomfort.

Table 6. Weighting and Ranking of the Architectural Sub-components of Residents' Acoustic Comfort

	Sub-component	Rank	Mean Rank	Degree of Freedom	Chi-Square	Significance Level
Architectural Sub-components of Residents' Acoustic Comfort	Source and External Zoning	1	9.95	10	3507.012	0.000
	Features of the Sound Receiving Location	2	9.79			
	Characteristics of the Sound Propagation Path	3	9.45			
	Space Syntax- Propagation of Sound from Outside to Inside	4	7.76			
	Space Syntax- Influence of Indoor Space Sounds	5	7.31			

	Sub-component	Rank	Mean Rank	Degree of Freedom	Chi-Square	Significance Level
Architectural Sub-components of Residents' Acoustic Comfort	Acoustic Privacy to the Outside Space	6	5.66			
	Acoustic Privacy from the Outside Space	7	5.64			
	Materials- Wall	8	3.34			
	Materials- Roof	9	2.88			
	Materials- Floor	10	2.82			
	Noise Pollution Caused by Mechanical Installations and Indoor Equipment	11	1.42			

The results shown in tables 5 and 6 indicate that the component of controlling the outdoor noise pollution and its three sub-components, including source of the noise and external zoning, characteristics of the sound receiving location, and characteristics of the sound propagation path were the most effective components on disturbing the acoustic comfort of the residents. The first sub-component (the source of the noise and external zoning) refers to the existence of streets, stadiums, schools, and any external factor that causes noise pollution for residents, which is generally related to macro policies in urban planning and the lack of acoustic comfort maps in land use based on non-sensitive, semi-sensitive and sensitive uses. Therefore, assigning the highest mean to this sub-component was not far from expected. The second most effective sub-component on disturbing the acoustic comfort of the residents according to table 6 is related to the control of noise pollution in the receiving area, which is generally due to the selection of inappropriate materials in the outer shell, the lack of use of double-glazed windows, and the failure in sound insulation of the walls. According to Table 6, the noise propagation path was the third effective sub-component due to the lack of use of plant covers, the use of sound absorbers, and sound barriers in the path of sound propagation to reduce the sound intensity.

According to the results shown in Table 5, spatial planning is the second most effective component on disturbing acoustic comfort (space syntax). Also, the results shown in Table 6 show that the inattention to the house's space syntax in terms of the distance from the source of outdoor noise pollution in the design of the building plan (for example, the bedrooms adjacent to the street) ranks fourth among the sub-components that disturb acoustic comfort. Inattention to the acoustic behavior of the indoor spaces and their influence on each other in the design of the building plan, as the second sub-component of the space syntax, ranks fourth. It seems that the sound disturbance by the neighboring rooms and spaces in the house such as the kitchen (the sound of washing dishes), the living room (the sound of the television, the conversations of family members), the children's playroom (the sound of playing and watching cartoons), has led this sub-component to rank fifth among the eleven sub-components.

According to the results shown in Table 5, the privacy index ranks third, and according to the results shown in Table 6, privacy to the outside or actually the propagation of sound from inside the house to the outside and privacy from the outside, the propagation of the neighboring spaces' sound (talking, walking, etc.) to the inside are in the sixth and seventh places. According to the results shown in Table 5, the effect of materials and execution techniques, such as hearing the sound of walking or the sound of conversations on other floors ranks fourth due to the use of inappropriate materials and poor execution techniques for the wall, roof, and floor, which led to the residents' dissatisfaction with the walls more than the roof and the floor. According to the results shown in table 5, indoor noise pollution ranked fifth, and based on the results in table 6, the noise made by the mechanical installations and equipment (elevators), ducts, dishwashers, washing machines, etc., is in the eleventh place which shows that the level of dissatisfaction with noise pollution resulting from these components is much lower than other components. Figure 9 shows the weighting and ranking of the architectural micro-components affecting the acoustic comfort of residents.

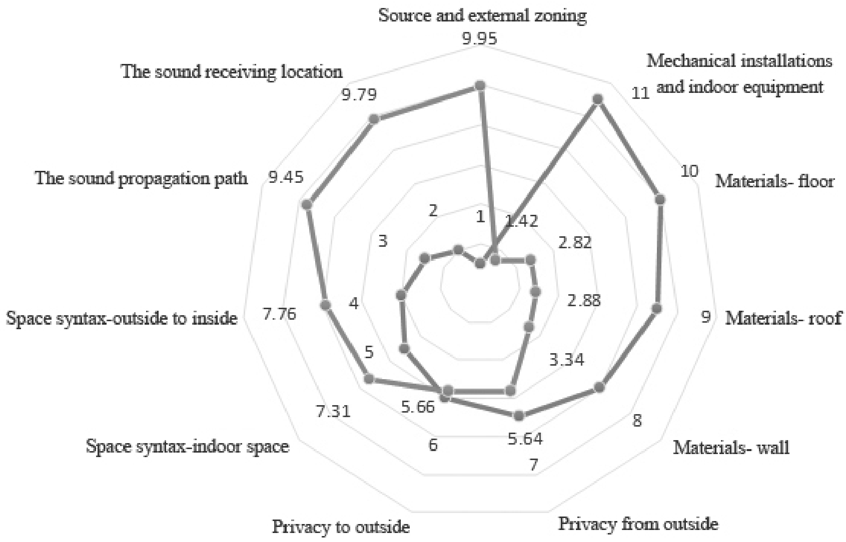


Fig. 8. Weighting and Ranking of the Architectural Sub-components of Residents' Acoustic Comfort

As can be seen in Figure 8, among the components that disrupt acoustic comfort, the source of sound production and external zoning is the most effective with a rank mean of 9.95, which is generally out of the control of the designing architects. However, the second component, which is the location receiving noise pollution caused the most dissatisfaction with a rank mean of 9.79. Sound pollution control in the receiving location can be done through double-glazed walls, the use of suitable materials, and double-glazed windows. In the following, the effects of the double-glazed window component on the acoustic comfort of the residents has been determined by the EEG method. To do so, in the second part, the reaction of the body and the brain to hearing the sound in two cases of using a double-glazed window and not using it have been investigated. These measurements can provide designers and planners with new information in the field of noise pollution control at the receiving location and the appropriate sound level. To do so, at first, the reaction of the person when facing the sound in the frontal and prefrontal lobes was investigated. Based on the examination of brain maps (colored heads), the absolute power of the alpha and theta bands related to the sample people, in two states of rest (without traffic noise) and the state of hearing traffic noise, was formulated in Table 6.

Table 7. Absolute Power of Alpha and Theta Bands in the Two States of Resting (without Traffic Noise) and Hearing the Traffic Noise

CASE NUMBER	Resting State		Hearing the Traffic Noise	
	THETA	ALPHA	THETA	ALPHA
CASE 1	FP1, F8	FP1, F8, T4	FP1, F7, F8, T4	F7, F8, T4
CASE 2	F7	F8, T4, T6, O2, O1	FP1, F8	F8, T4, T6, O2, O1
CASE 3	FP1, F4	C4, O2	FP1	O2
CASE 4	F7, F8, T4	T4	F7, T4	T4
CASE 5	F7, T4, O1	FP2, F3, F4, C4, T4	F7	FP2, F3, F4, T4, C4
CASE 6	F3	F3	F3	F3, F8, O2
CASE 7	T6	T6, F7	F4	F4, O2
CASE 8	F4, F8	F8, T4, T6, O2	C3, FP2, F8	FP2
CASE 9	F3, FP2, F8	F3, FP2, F8, T6, O2	F7	F7, F8, O2
CASE 10	FP2	FP2, T4	FP2	FP2, F8, T4
Regions with the Highest Numerical Increase	F7	F8, T6, O2	FP1, F8	FP2

Based on the results obtained from Table 7, in the state of hearing the traffic noise, in the theta frequency band, the FP1 and F8 regions, and in the alpha frequency band, the FP2 region had the highest numerical increase compared to the resting state. This means that alpha and theta activity in the FP1 and FP2 points were dominant in the traffic noise state compared to the resting state, noting that these points are mainly involved in the control of attention. To better understand the above table, the brain map of the alpha and theta bands related to subjects No. 3, 8, and 10 when hearing the traffic noise is shown in Figure 9. The points that had a red color spectrum in these colored heads have been identified as the points that had the most activity and increase in the frequency band.

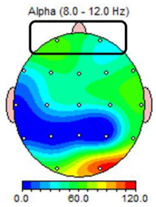
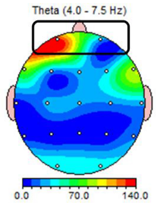
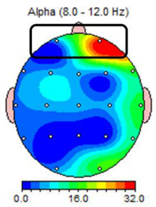
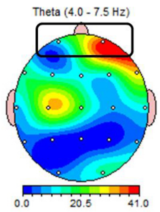
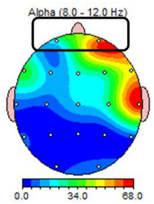
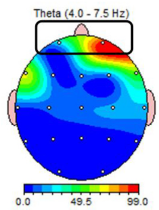
CASE NUMBER	ALPHA	THETA
CASE 3		
CASE 8		
CASE 10		

Fig. 9. The Brain Map of the Alpha and Theta Bands Related to Cases No. 3, 8, and 10 When Exposed to Traffic Sound

The areas drawn around them are the two points FP1 and FP2. The red color in each of these two areas indicates an increase in the frequency band.

This shows that the frequencies of slow bands such as theta and alpha have the highest spectral values in the frontal pole region, and this means that exposure to traffic noise potentially represents a decrease in the level of sustained attention and at the same time leads to attentional bias. Attentional bias is a type of cognitive bias that leads to a change in the focus of attention. Cognitive biases resulting from disturbing noises are mental errors, which systematically lead to a wrong attitude or tendency, and affect the reasoning, decision-making, cognition, and perception of a person, causing deviation from reality, and ultimately making a person irrational, weak, or incorrect in his decisions. In other words, despite the person's efforts to ignore and not pay attention to the sound stimulus, the attentional bias in the person's brain is directed towards the sound, and finally, this factor plays an important role in many psychological pathologies and stress disorders.

According to the evidence available in the research on cognitive neuroscientists, it is assumed that theta and alpha wave oscillations are mainly related to emotional memory processing in the left frontal-temporal cortex areas. Therefore, the power ratio of alpha and theta waves in the T3 region was investigated as one of the key points in the temporal cortex. The power ratio measures the ratio between waves. In fact, if the power ratio of a wave is small compared to other waves, it will be dominated and influenced by them, and it means that it will lose its effectiveness. To analyze the relative power, the brain maps (colored heads) of the samples in both conditions were examined. The color of the T3 area in each of the maps in two states of resting and hearing traffic noise is provided in Table 8. Also, for quantitative analysis, each color was assigned a number based on the Likert scale.

Table 8. Power Ratio of Theta to Alpha

CASE NUMBER	ANALYSIS	REST	TRAFFIC
CASE 1	Qualitative	GREEN-YELLOW	ORANGE
	Quantitative	2.5	4
CASE 2	Qualitative	RED	GREEN
	Quantitative	5	2
CASE 3	Qualitative	YELLOW	ORANGE
	Quantitative	3	4
CASE 4	Qualitative	YELLOW-GREEN	GREEN
	Quantitative	2.5	2
CASE 5	Qualitative	YELLOW-GREEN	BLUE
	Quantitative	2.5	1
CASE 6	Qualitative	ORANGE	GREEN
	Quantitative	4	2
CASE 7	Qualitative	RED	ORANGE
	Quantitative	5	4
CASE 8	Qualitative	GREEN	BLUE
	Quantitative	2	1
CASE 9	Qualitative	GREEN-YELLOW	GREEN-BLUE
	Quantitative	2.5	1.5
CASE 10	Qualitative	GREEN	GREEN
	Quantitative	2	2
AVERAGE		3.1	2.3

Likert scale: 

The mean numerical results in Table 8 show that the power ratio of theta compared to alpha in the resting state was 3.1, which decreased to 2.3 in the state of hearing the traffic noise. To better understand Table 7, the color maps related to the power ratio of theta compared to alpha in two test subjects Nos. 2 and 6 in two states of resting and hearing traffic noise in the T3 area are presented in Figure 10.

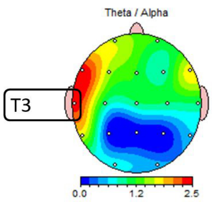
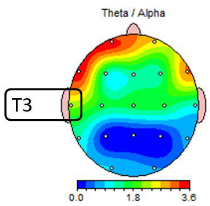
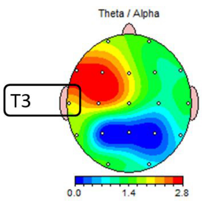
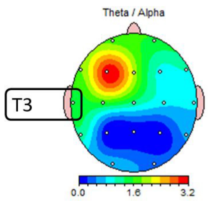
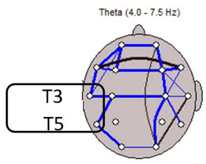
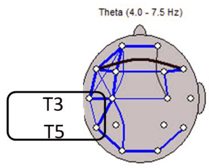
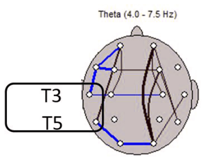
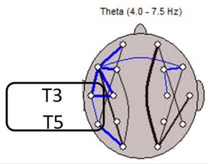
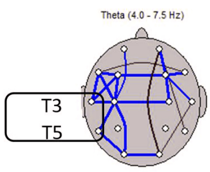
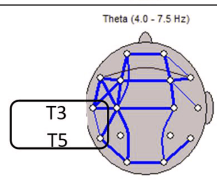
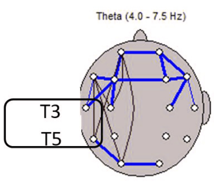
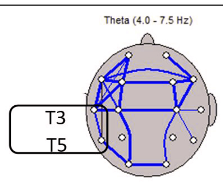
CASE NUMBER	RESTING	TRAFFIC
CASE 2		
CASE 6		

Fig. 10. Color Maps of Power Ratio of Theta to Alpha for the Two Cases Nos. 2 and 6 in the Resting and Hearing Traffic Noise States

The T3 region in case No.2 is red in resting state and green after hearing traffic noise. Also, this point changes to orange in person No.6 and green after hearing traffic noise. This color change from red and orange spectrum to green shows the reduction of theta to alpha power ratio in point T3 when the cases are exposed to noise Traffic. Through the examination of the power ratio of theta and alpha waves in the T3 region as one of the key points in the temporal cortex which is related to auditory and emotional-cognitive processing, the results in Table 8 and Figure 10 show that when people are exposed to traffic noise, at the T3 point, theta power decreases compared to alpha power and causes disruption in emotional memory processing and ultimately disruption in cognitive processes. Here, emotional memory refers to a person's positive or negative emotional responses when dealing with a sound stimulus. Cognitive processes are incomplete regardless of the emotional state, and somehow, emotion and cognition are closely related and complement each other.

As mentioned in the previous sections, the temporal lobe of the brain, which is located around the temple, is responsible for the primary processing of hearing. By examining coherence and its level between different points in this area of the brain, it is possible to understand the connection between different areas in the temporal part of the brain and how much energy is shared between different parts. Figure 11 shows the coherence between the two points T3 and T5 related to cases No. 3, 5, 8, and 9. Blue lines mean less coherence and red lines indicate more coherence. Also, the narrower the lines, the less coherence, and with the increase in the thickness of the line, the coherence increases.

CASE NUMBER	REST	TRAFFIC
CASE 3		
CASE 5		
CASE 8		
CASE 9		

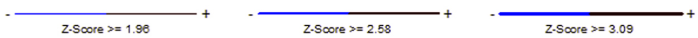


Fig. 11. Coherence between Two Points of T5 and T3 for Cases Nos. 3, 5, 8, and 9

Figure 11 shows that there is no coherence and connection between the two points T3 and T5 in the resting state (there is no line between the two points), but as soon as the sound of traffic is heard, this connection is established (the two points are connected through a blue line). Also, more accurate results can be obtained through quantitative analysis (Table 9) and the degree of coherence. High coherence indicates that some parts of the brain are so stuck together and have coherence, that they do not have the necessary ability to break this connection and communicate with other parts of the brain, and low coherence means that brain resources are unable to connect some areas. Table 9 deals with the quantitative analysis of the coherence between T3 and T5.

The mean values in Table 9 show that the coherence value between T3-T5 in the alpha wave in the resting state was 17.765 and after hearing the traffic sound, it was 22.54, which is indicative of an increase in the alpha value in the exposure state. In other words, when exposed to noise, the level of coherence between T3-T5 (two important points in auditory, cognitive, and emotional processing) in the alpha wave increases, and the increase in the amount of alpha when exposed to traffic noise can potentially affect emotional memory processing, and it is likely to cause disturbances and affect the cognitive and emotional organization of the residents.

The results of this research indicate the reduction of concentration, attentional bias, and disturbance in the cognitive-emotional organization of the residents as the main psychological consequences of exposure to noise in a residential space, which leads to the undesirable and negative emotions. As a result, it is a response to the negative perception of environmental conditions by people and is considered a danger threatening the health of the residents, and as a result, disrupting their performance. Undoubtedly, the effects of noise is not merely limited to these categories, and according to the results of other researchers, it seems that it will affect the cardiovascular system, the endocrine system, and the sleep quality of the residents. Thus, it is suggested that young researchers, in future research, explore and investigate the relationship between the above effects and the results of neuroscience analyses in this research and complete the achievements of this topic.

Table 9. Level of Coherence between T3 and T5 Points

CASE NUMBER	RS	TRAFIC
CASE 1	26.97	40.2
CASE 2	12.77	20.68
CASE 3	9.33	9.83
CASE 4	11.22	28.02
CASE 5	31.7	34.46
CASE 6	24.01	20.88
CASE 7	10.52	15.08
CASE 8	26.24	27.73
CASE 9	13.47	14.61
CASE 10	11.42	13.91
AVERAGE	17.765	22.54

6. CONCLUSION

The increasing population growth, the industrialization of the cities, the increase in pollution, and the environmental issues have caused fundamental and special problems in the quality of life and biological health of humans. Noise pollution, as a part of the aforementioned problems, can have dangerous effects on human health in both auditory and non-auditory forms. On the other hand, the design and construction of residential buildings are associated with functional, economic, and complex requirements, which are generally preferred over other design considerations such as paying attention to acoustic, thermal, and visual comfort, etc. Noise pollution control and sound engineering, as important considerations in design, are often taken as marginal topics in the process of planning, design, and finally construction. This issue makes the acoustic comfort and the improvement of residential environments a costly process, and at best, it is provided through interventional measures, which are generally realized after construction or during use. The results of this research showed that in the investigation of the components that disturb acoustic comfort, outdoor noise pollution is in the first place, space syntax is in the second place, the privacy index is in the third place, and materials and executive techniques is in the fourth place. Finally, indoor noise pollution was identified as the weakest disturbing component affecting the acoustic comfort.

Also, in the following, the effects of using a double-glazed window as one of the solutions to control the outdoor noise in the receiving location on the acoustic comfort of the residents were evaluated by the EEG method. The results of this study showed that if the background noise level increases from 40 dB (Iranian National Building Code) to 53 dB, it seems to lead to a change in focus and attentional bias and disrupts the emotional and cognitive organization of people. Now, if sound control management is taken into consideration in the initial stages of planning, ideation, and design of residential buildings, it seems that it can solve the above problems.

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7. SUGGESTIONS

Optimal sound management and provision of acoustic comfort include a wide range of considerations and options, which are briefly suggested for the designers.

1. Macro policies in urban planning including the preparation of a noise pollution zoning map for urban areas and the extraction of an acoustic comfort map for the urban land use based on sensitive, semi-sensitive, and non-sensitive uses to noise pollution.

2. Spatial planning based on the acoustic behavior of the spaces, for example, paying attention to the noise pollution caused by indoor factors such as the kitchen (the sound of washing dishes), the living room (the sound of the television, the conversations of family members), the children's playroom (the sound of playing and watching cartoons), controlling vibration and sound pollution from mechanical installations and equipment (elevators), reducing the noise of ducts, etc. In general, spatial planning should be done in such a way that the following goals are pursued:

A) Preventing the entry of noise pollution produced outside the building into different interior spaces

B) Preventing the influence of noise pollution in the interior spaces of a building on each other

C) Preventing the propagation of noise pollution from inside the building to the environment and the surrounding space.

3. Selection of materials: The selection of suitable materials in the three areas of the roof, wall, and floor of the building, which is suggested to be considered from the beginning of the design process until construction, to reduce noise pollution.

4. Controlling outdoor noise pollution: To control outdoor noise pollution, three main solutions can be used:

A) Controlling and reducing the noise from the source of noise pollution: future highways or airports, traffic control of vehicles, reducing the sound of facilities inside the complex, etc.

B) Control and reduction of noise pollution in the path of sound propagation including the use of plant covers, design of the area, use of sound absorbers, etc.

P) Controlling and reducing noise pollution in the sound receiving location: using double-glazed windows, designing the exterior form and proper view, choosing suitable materials for the outer shell, and implementing sound insulation details in the walls.

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