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A BASIC STUDY ON THE SOUND ABSORBING PROPERTIES OF SQUARE PANELS WITH HOMOGENEOUS SIZE AND VARIOUS ARRANGEMENTS

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Abstract: *Noise disturbance at airports negatively affects people's health. This paper focuses on the study of the public spaces with a large capacity in the Ahvaz International Airport, which are perceived as acoustically uncomfortable. The main reason for poor acoustic conditions is an excessive Hall reverberation, as the measured reverberation time reached 4–5 s at middle frequencies. To overcome this acoustics problem, five square sound absorbing panels were installed on the wall surfaces of the airport lounge and the models were simulated by using EASE 4.4 software. In our research Revebration Time (RT, or main index), three other sound indices including, auditory error coefficient (AL_{conse}) speech transmission index (STI) and total sound pressure level (SPL) were evaluated according to the international standards of ISO3382 and ISO 3382-1. The aim of this research was to introduce an acousticc treatment on the airport lounge walls to enable better absorption of sound to improve the acoustic quality of Ahvaz International Airport. After the simulation, it was concluded that of the five different square panels deployed, Model SA-1 was associated with the lowest sound pressure across different frequencies and hence this panel was considered as the ideal for improved acoustics for the space.*

Keywords: *Acoustics, Flight lounge, Noise, Sound absorbing, square panels, Reverberation time.*

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1. INTRODUCTION

The expansion of airports and the increase in the number of domestic and international flights in most countries have forced researchers and engineers to search for ways to improve the comfort and convenience of passengers [1]. Noise pollution is a growing environmental problem and a serious health hazard [2]. Hume [3] in a statistical study in a large British airport found that noise is a relatively neglected subject. Other studies [4,5] unanimously concluded that if the sound absorption is neglected the emission level will greatly increase.

Kanev [6] was noticed that large-volume spaces without a sound-absorbing treatment were acoustically uncomfortable. The spaces were too reverberant and noisy, speech intelligibility was usually low. Calculations showed that good acoustic conditions could be provided only by using absorbing panels which are placed on the ceiling and walls.

Job [7] showed that there is a clear and positive relationship between sound level and complaints.

Campbell et al. [8] experimentally studied the effects of different sound behaviours in a multipurpose room used for speech activities. For this purpose, measurements of reverberation time, speech clarity and sound pressure level were performed. Their results showed that the acoustic treatment was possible by using a suspended absorbent ceiling with a sound absorbent carpet and wall panels. Inserting furniture would add some sound scattering effect which mainly shortens the reverberation times and increases speech clarity.

Russo and Ruggiero [9] compared two different sound absorption scenarios in a medium size class by simulation. They built a detailed 3D classroom model and then simulated the considered configurations by using a provisional software (CadnaR), and placed sound absorbing panels appropriately on the walls and the ceiling. This enabled them to obtain optimal acoustics in school setting at a reasonable cost.

The configuration of sound absorbing panels was investigated in other studies. For example, Parkinson [10] indicated that configuration influences absorption. In another example, it was proven that honeycomb panels with a paper core absorbed better sound in the range between 1 and 2 kHz. Panels with significant exterior surface irregularities had the best acoustic characteristics at a frequency of 4 kHz [11].

Trinh et al [12] indicated that the optimal geometrical parameters of perforated panels and the cavity depth maximized sound absorption and the corresponding sensitivity indices under normal condition. The lattice and linear alternate layouts of absorbing panels on the wall are other factors that are effective on the level of the absorption of sound energies and the increase of sound absorption efficiency [13]. In another investigation, it was shown that the characteristics of geometric parameters in the ceiling of mosques show different sound behaviour [14].

The prediction of noise level with too many people speaking in a room depends on the number of speaking persons, the room size, and the equivalent absorption area [15]. The segmentation, distribution, and layout of absorbent panels on the walls have been shown that the estimation of the reduction in sound intensity level depends on the absorption coefficient, dimensions, and installation location of the panels [16]. Therefore, the number and location of resources and receivers have slightly affected the results [17].

Changing items that affect the amount of absorption, produces significant changes in Reverberation Time (RT) and (SPL) Sound Pressure Level (SPL) and is more noticeable in RT [13]. Low RT leads to a low sound pressure level [18].

The purpose of this study is to investigate different configurations of various sound absorbing panels to find an optimal acoustic behaviour in Ahvaz International Airport (AIA), which would be a novel approach for ab airport in southwest of Iran. Furthermore, the use of various sound absorbing panels that could passively absorb sound energy for is discussed to improve the acoustic quality of the passenger Hall.

2. MATERIALS AND METHODS

In this work, the flight Hall of Ahvaz Airport was considered as a case study. The method in this research, due to its interdisciplinary nature, was a combination of experimental research, simulation and case study. In the first stage, using an experimental strategy, effective independent variables were identified, and research models were designed. For this purpose, four acoustic indices (RT, STI, SPL, and auditory error coefficient or) were studied as different variables.

The physical structure of different the sound absorption panels was studied as an independent variable. The amount of noise in the flight Hall was dependent on the geometry of the absorbing panels. The Brüel & Kjær Model 2260 B&K sound level meter was used to study noise fluctuations.

In the next step, EASE software was used as the simulation procedure. Since the EASE software does not accept more than 35,000 levels for analysis, the model performed in AutoCAD and is drawn using a simpler model.

The interior spaces of Ahvaz Airport have been designed and executed using light walls and partitions. The airport has installed inefficient acoustic tiles and unsuitable materials such as composite and stone, which are not effective in reducing noise pollution and lead to an increased noise reversal. We expect that the results obtained from our research can be applied to the flight Halls of other Iranian airports.

3. ACOUSTIC INSULATION EVALUATION

In this study, five different configuration designs of sound absorbing pieces (Fig.1) for the walls were examined and the layouts were identified (A-L, Fig. 2). To reduce the level of sound pressure in an enclosed space, we selected the sound absorbing panels made from wood with similar properties. Each square panel had a dimension of 0.115 by 0.115 meters. By simulating different absorption panels installed to the of the airport lounge, the following sound indices (RT, STI, SPL and) were measured using EASE software, version 4.4.

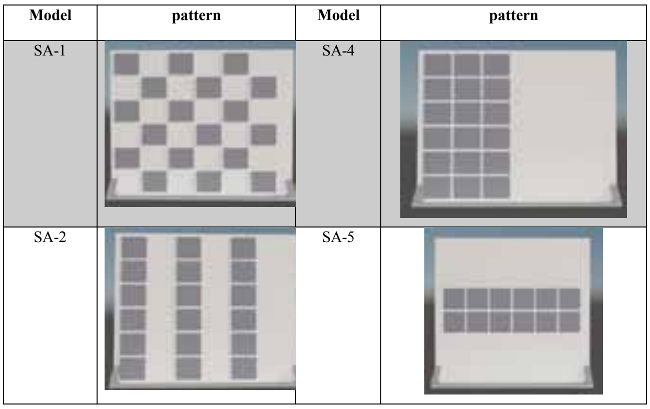

Fig. 1: Introducing the models (SA-1 to SA-5), each with a different pattern. The area of a single square panel is 0.115 by 0.115 meters.

4. FORMULATIONS

According to ISO 3382-1, RT is considered as the dominant indicator of a room's sound quality for music or speech. RT is the time when the sound pressure level drops to 60 decibels after sound energy decays in the room. The standard DIN 18041 defines optimal T values for different activities in a room.

According to the law of Eq, the RT can be estimated by Sabine's law which states that there is an inverse relationship between reaction time and sound absorption at the surface, which is as following : (1)

$$RT_{60}=0.161\frac{V}{A} \tag{1}$$

Where

V is the volume of the room in cubic meters and

A is the amount of sound absorption in the whole room, Coefficient is 0.161 with respect to temperature of 55.3° C.

$$A = (A_1.\alpha_1 + A_2.\alpha_2 + A_3.\alpha_3 + \cdots + A_n.\alpha_n) \tag{2}$$

In this formula

A_n is the absorption coefficient of the sound and

α_n is the absorption coefficient of the sound material.

The average RT ($R_{Taverage}$) is calculated using the following formula: (3)

$$RT_{average} = \frac{RT300+RT500+RT1000+RT2000+RT4000}{5} \tag{3}$$

The change in the amount of absorption causes significant variation in the amount RT and SPL, where the variation in RT is more noticeable [19]. Tab. 1 presents the parameters proposed by the ISO/DIS 3382- 1:2009 standard. According to this standard table, if an STI between 0.45 to 0.60 is achieved it can be considered as satisfactory, and numbers higher than 0.75% are regarded as excellent level of this index [20].

Qualitive evaluation of intelligibility STI	Qualitive evaluation of intelligibility (subjective impression)
0.75-1.00	Excellent
0.60-0.75	Good
0.45-0.60	Satisfactory
0.30-0.45	Poor
0.00-0.30	Very poor

Tab. 1: Degree of speech intelligibility evaluated by the STI according to ISO3382

Speech intelligibility is described as the ability of the listener to understand the speech. The speech intelligibility ability is a measure of the effectiveness of the speech. Absolute measurement of intelligibility is very complex and is related to the science of psychoacoustics. To estimate it, the following formula is used and the results are compared using the values given in Tab. 2.

$$\%AL_{CONSE} = (170.5405)e^{(-5.419*STI)} \quad (6)$$

$$STI = 1 - 0.46\log(AL_{CONSE}) \quad (7)$$

AL_{CONSE} value (% range)	Subjective intelligibility impression
0-3	Excellent
3-7	Good
7-15	Acceptable
15-33	Marginal
33-100	Bad

Tab. 2: Description of the articulation loss of consonants (% AL_{CONSE})

According to Tab. 2, an articulation loss coefficient (**% AL_{CONSE}**) in the range of zero to 15 percent defines the ideal articulation loss (21).

5. RESULTS

The simulated models which are introduced in Fig. 1, have been obtained after multiple testing. To validate the results, simulations in the Hall of the airport with empirical test flight were conducted in this case study. According to Fig. 3, Model SA-1 had the most uniform distribution for the frequencies studied here, and had the lowest sound pressure level, while Model SA-5, had the least uniform distribution for most frequencies.

Tab. 3 lists the results of field survey including the SPL measurements for the five octave bands from 300 Hz to 4000 Hz taken at the 12 locations in the most critical acoustic condition from 8 am to 2 pm at AIA.

Based on the following results obtained the sound measuring device, B&K, the maximum value equivalent to Leq sound measured 86.5 dB, the maximum LA value of 84.3 dB, the minimum Leq value of 82.6 dB the lowest LA level was 80.9 dB the AIA passenger Hall is not in an acceptable acoustic condition.

Row	Measured location	Maximum	Minimum	Frequency (Hz)				
		Leq	LA	300 dB	500 dB	1000 dB	2000 dB	4000 dB
1	A	86.5	84.3	59.6	66.5	70.3	70.3	68.9
2	B	82.7	81	59.8	66.6	70.1	70.5	68.9
3	C	82.7	81.2	59.7	66.7	70.3	70.3	70.9
4	D	82.9	81.4	59.8	66.7	70.5	70.4	68.9
5	E	83.1	81.4	60	66.6	70.1	70.4	68.9
6	F	83.1	81.5	59.7	66.5	70.4	70.3	69
7	G	83.3	81.6	60.1	66.6	70.2	70.3	68.8
8	H	83.5	81.8	59.5	66.6	70.6	70.4	68.9
9	I	83.5	81.6	59.8	66.4	70.2	70.3	68.9
10	J	83.8	81.7	60	66.8	70.2	70.3	68.8
11	K	83.1	81.3	60.1	66.8	70	70.3	68.9
12	L	82.6	80.9	59.8	66.7	70	70.3	68.7

Tab. 3: The SPL measurements for the 12-area in the Ahvaz International Airport (300 Hz to 4000 Hz).

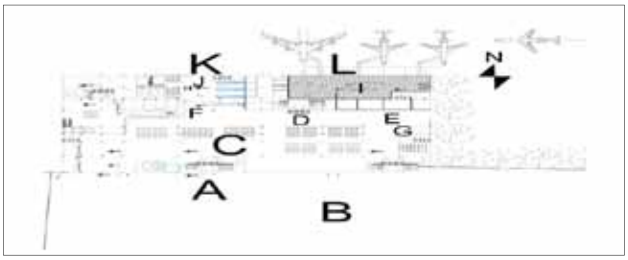

Fig. 2: The layout of spaces in Ahvaz International Airport. The area under study is marked by cross-hatching. A to K refer to the position of the sound measuring device, Brüel & Kjær Model 2260 B&K

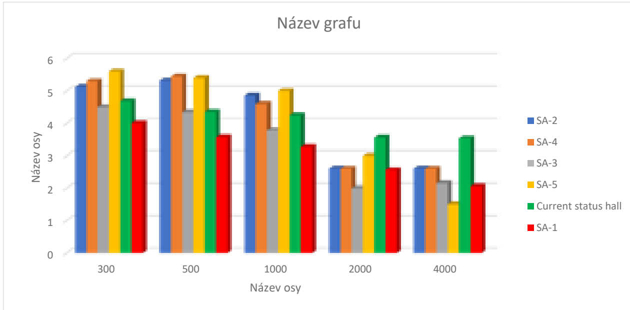

Fig. 3: Comparing the RT for different Model panels (SA1 to SA5) as simulated for the Airport Hall. The green data shows the current status of RT in the Airport Hall at frequencies 300-4000 Hz

After analyzing sound absorbing panels in Fig. 3, this was concluded that Model SA-1 had an appropriate behavior, especially at a frequency around 2000 Hz. Other panels (Models SA-2, SA-3 and SA-4) absorbed sound almost similarly. However, Model SA-5 does not show a significant percentage of noise reduction.

Frequency (Hz)	300	500	1000	2000	4000
Current airport status Hall	4.68	4.35	4.25	3.57	3.54
Virtual Hall with SA-1	3.75	3.58	3.28	2.56	2.06

Tab. 4: Comparing the RT of current Ahvaz airport Hall (I in Fig. 1) to the virtual design using square panels Model SA-1 in different Frequencies

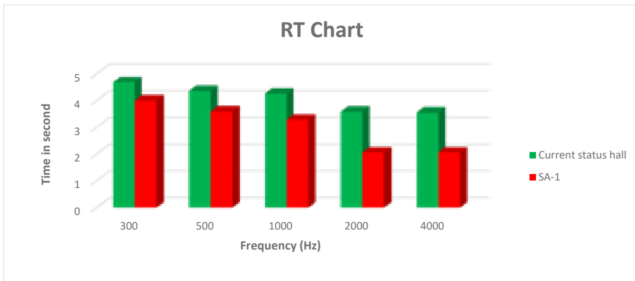

Fig. 4: Comparing the RT of current status Hall of Ahvaz Airport (Green color) to the virtual design square panels Model SA-1 (red color) in Frequencies from 300 Hz to 4000 Hz

As indicated in Fig. 4 and Table 4 by using the square panel Model SA-1, the RT level which is the main parameter of this study, decreased significantly from a maximum of 4.68 to 3.75 in 300 Hz frequency. Based on the calculations with the formula below, the average RT of the simulated airport Hall is 3.09, which shows a suitable value for a large-volume airport Hall when using public hypothetical speakers.

$$RT_{average} = \frac{RT300+RT500+RT1000+RT2000+RT4000}{5} = 3.09 \quad (8)$$

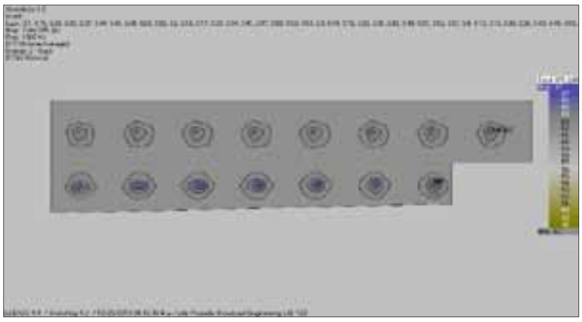

Fig. 5: The Sound Pressure Level (SPL) of the Current status Hall has been illustrated by showing public address loudspeakers via graphical contours

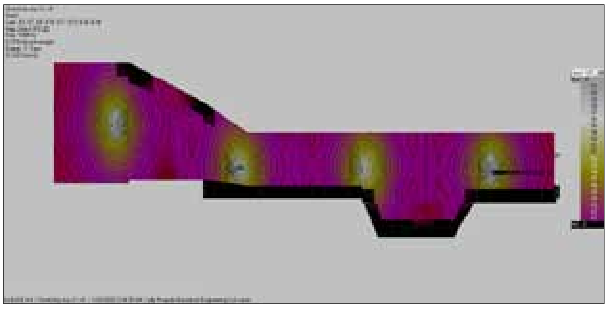

Fig. 6: The SPL of the designed Hall (Model SA-1) has been illustrated by showing hypothetical public talkers via graphical contours

For the total SPL (Fig. 5), the minimum amount of sound pressure level in the airport Hall was 48 dB and the maximum total sound pressure was 67 dB. When this is compared to the proposed Hall design with the absorption Model SA-1 (Fig. 6), the minimum value obtained is 41 dB and the maximum is 61 dB, which is less than 65 dB in the SPL range and has been improved by about 7dB.

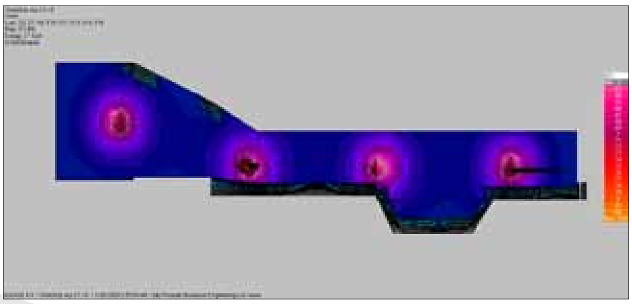

Fig. 7: Illustrating the simulation of STI the after installation of panels Model SA-1. The graphical contours represent sound from public hypothetical talkers

Based on the simulations by using Model SA-1, the Speech Transmission Index (STI) value in the Hall varied between the range of 0.63 to 0.82 units (Fig. 7). Therefore, according to the standard of Tab. 1, the simulated design Hall stands between 'Good and Excellent' position in terms of sound transmission behavior.

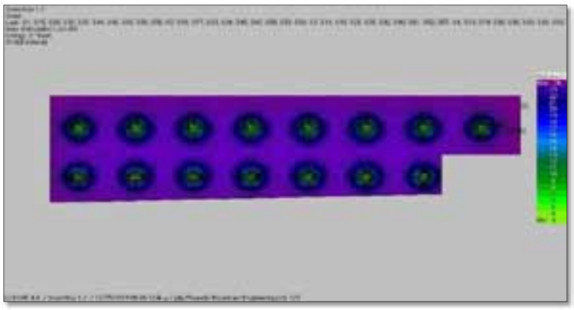

Fig. 8: Illustrating the ALconse of the current status Hall. Sound represented by these graphical contours reflects the sound from public address loudspeakers

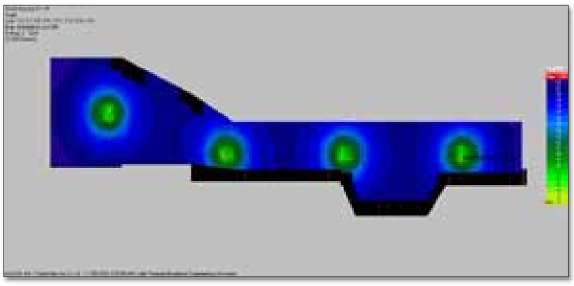

Fig. 9: Illustrating the simulation of ALconse in the presence of Model SA-1 in the design Hall. The graphical contours represent sound from public hypothetical talkers

The ideal status of the auditory loss has been defined to have an $\boldsymbol{AL_{CONSE}}$ in the range of zero to 15% [24]. In our study, the measurement for $\boldsymbol{AL_{CONSE}}$ in the current status Hall (Fig. 8) was between 4% to 34%, while in the design Hall this measurement was between 3% to 22% (Fig. 9). The overall indication is that the $\boldsymbol{AL_{CONSE}}$ is in a good and marginal position (Tab. 2). Therefore, the auditory loss coefficient in the designed Hall using Model SA-1 has been reduced by 12%.

6. DISCUSSIONS

In order to accurately evaluate the experimental data obtained from measurements and validations (Table 3) towards the acoustic study of AIA, simulations were performed as a case study. The purpose of this research was to find the best geometric form for sound absorbing panels using simulation.

The frequency range selected to simulate the flight Hall is shown in Fig. 3 with a cross-hatching. In the present study, the sound level in all 12 locations was higher than the environmental standard. The findings of this study showed that the equivalent sound pressure level in all measuring stations and in all time, periods was higher than the allowable sound limits.

In a further study, geometric modelling and networking of sound absorbing panels were determined as shown in Fig.1.The data obtained from experimental tests (Fig. 2 and Fig. 3) showed that Model SA-1 compared to other models, has the best performance at all frequencies.

In similar studies, honeycomb panels [11], as well as lattice and linear alternate layouts of absorbing panels [13] produced similar results in reducing sound energies and an increase in sound absorption efficiency. It can be concluded from our research, that more scattered absorption panels with square geometry and a more regular arrangement, achieved a more effective result of noise reduction. Additionally, the RT and sound absorbing panel of Model SA-1 were especially satisfactory in the range from 500 Hz to 4000 Hz as compared with other models (Fig. 3).

Most studies have focused on textile and material which are used in sound absorbing panels or the location of the installed panels. In most praying Halls of mosques in Iran, fabrics and textiles have been installed on walls primarily as religious quotations. It will be interesting to learn how these fabrics can improve the acoustic behavior of the Hall (see also Elkhateeb and Eldakdoky, 2021).

7. CONCLUSIONS

The acoustic of airports is an important factor that helps determine a comfortable environment for passengers. This study, like many others, shows that large-volume spaces without a sound-absorbing treatment are always acoustically uncomfortable. Our overall purpose was to develop a systematic approach to audio design for noise pollution reduction in the passenger Hall of Ahvaz airport (AIA).

Speech intelligibility is usually low in the spaces which are too reverberant and noisy. Our study showed that in order to improve the acoustic condition of AIA, a significant part of the space surfaces should be covered by the absorbing materials.

In this investigation, the simulation of eight different configuration models of adsorbent panels with square geometry was performed with EASE4.4 software. It was found that Model SA-1 has the best performance based on the four acoustic indices. The acoustic indices including reverberation time, sound pressure level, auditory error coefficient and speech transmission index have been improved in the simulated model of AIA with modeled by sound absorbing model.

In addition, further studies are needed to significantly improve the sound quality environment of airport terminals by studying more closely other physical elements that shape the spaces through improvement in acoustic conditions. We recommend that future studies should be towards finding optimal dimensions and locations to install appropriate sound absorbing panels.

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