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The Effects of Spatial Dimensions and Relocation and Dimensions of Sound Absorbers in a Space on the Objective Parameters of Sound

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Abstract**—**This study investigated the differences in the objective parameters of sound depending on the changes in the lengths of the lateral surfaces of a space and on the replacement of the sound absorbers that are placed on these surfaces. To this end, three models of room were chosen. The widths and heights of these rooms were the same but the lengths of the rooms were changed. The smallest room was 8 m. wide and 10 m. long. The lengths of the other two rooms were 15 m. and 20 m. For each model, the differences in the objective parameters of sound were determined by keeping all the material in the space intact and by changing only the positions of the sound absorbers that were placed on the walls. The sound absorbers that were used on the walls were of two different sizes. The sound absorbers that were placed on the walls were 4 m and 8 m. long and story-height (3 m.). In all model room types, the sound absorbers were placed on the long walls in three different ways: at the end of the long walls where the long walls meet the front wall; at the end of the long walls where the long walls meet the back wall; and in the middle part of the long walls. Except for the specially placed sound absorbers, the ground, wall and ceiling surfaces were covered with three different materials. There were no constructional elements such as doors and windows on the walls. On the surfaces, the materials specified in the Odeon 10 material library were used as coating material. Linoleum was used as flooring material, painted plaster as wall coating material and gypsum boards as ceiling covering (2 layers with a total of 32 mm. thickness). These were preferred due to the fact that they are the commonly used materials for these purposes.

Evaluations were made for Reverberation Time (T_{30}), Early Decay Time (EDT), Clarity (C_{80}) and Definition (D_{50}) effects of the different placements of sound absorbers on the objective parameters of the sound were established within the jnd values defined in the ISO 3382. The effects of the relocation of sound absorbers on the objective parameters of the sound were found to be below the jnd limits.

Keywords**—**Jnd, objective parameters of sound, room model, sound absorber

I. Introduction

SPACES with different functions have different acoustic needs. Acoustic needs can be evaluated/assessed through the objective parameters of sound that vary according to the changes in the form, material and volume of the space. The objective parameter values of sound of a space can be obtained during the design process either through computer modelling with software or by making their small models.

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The estimations made initially with the measurements on small models are now being made through computer modellings. In computer modelling, changes and tests are made easily, which is the main reason for the preference of computer modellings. The values of the objective parameters of sound can be obtained through different computer programs and in this study they were obtained through ODEON v10. Table I shows the values regarding the minimum jnd levels in the objective parameters of sound defined in ISO 3382 [1].

TABLE I
JND Values of per Objective Parameters of Sound

Parameter	JND (just noticeable difference)
Reverberation Time, T_{30}	5 %
Early Decay Time, EDT	5 %
Clarity Index, C_{80}	1 dB
Definition, D_{50}	5 %

The objective parameters of sound are taken into account in order to verify that the acoustically designed spaces have been designed to serve the functions for which they are to be used. Of the objective parameters of sound, the Reverberation Time (T_{30}), Early Decay Time (EDT), Sound Clarity (C_{80}), Definition (D_{50}), Lateral Energy Fraction (LF), Speech Transmission Index (STI) and Center Time (TS) values can be obtained in the modellings with the ODEON v10 [2], [3]. In this study, the T_{30}, EDT, C_{80} and D_{50} values were taken into consideration.

The reverberation time is important in spaces for both sound clarity and control over vibrant music. The reverberation time which is defined as the time in which the level of sound in a room to decay by 60 dB after the sound source is turned off is signified with T_{30} in the ODEON v10 [1], [4]. The EDT value which shows the effects of early reflections, and therefore the effects of the space, on the sound is equal to the time which is six times more than the elapsed time for a 10 dB decrease in the sound after the sound source is turned off [5]. D_{50} denotes the ratio of the sound energy that the receiver gets 50 ms after the sound that the receiver gets directly from the sound source to the total sound energy in a space, and is an objective parameter that is obtained to determine the sound precision [6]. C_{80} denotes the ratio of the sound energy that the receiver gets 80 ms after the sound that the receiver gets directly from the sound source to the sound energy that the receiver gets after the first 80 ms and is an objective parameter used to determine the vibrancy of the sound [7]. The jnd values represents lowest perceivable difference among different parameters and they were obtained in this study for the objective parameters of EDT, T_{30}, C_{80} and D_{50} [3], [4], [8] (Table I).

Klosak and Gade obtained the objective parameters of sound (Clarity, Strength, Early Lateral Energy Fraction) in 24 rectangular concert halls by using the ODEON computer simulation. They compared their findings with the regression models [9]. Lisa, Rindel and Christensen modelled to Aspendos Ancient Theatre in a computer program with two different details having simple and detailed models. They compared to the results belonging to objective parameters of sound (T30 and EDT) obtained from these models with measurement results. The comparisons of the all results were made in terms of jnd (just noticeable difference) [10]. Green, Barron and Thompson studied on the effect of scattering surfaces in rectangular concert halls with a scale model analysis. They placed eight scattering panels on the surfaces of a hall with different configurations. According to the results of research, changing of scattering surfaces affected to objective parameters of sound [11]. Nilsson investigated the effect of furnishing and different types of ceiling absorbers on objective parameters of sound. He performed the classroom in three general different configurations; 1. Classroom have suspended absorbent ceilings and furniture, 2. Classroom have suspended absorbent ceilings but it does not have any furniture, 3. Classroom does not have any suspended absorbent ceilings and furniture. He applied 92 configurations totaly. Results belonging to objective parameters of sound obtained in the different configurations were affected by changes [12]. Sakuma and Guo researched the effects of absorbing panels on acoustic quality in small rectangular meeting rooms. They selected three types panel with different frequency characteristics and they installed them on two parallel walls. Values belonging to objective parameters of sound changed with the relocation and change of amounts of sound absorbing materials [13]. Iannace, Trematerra and Qandil studied about the acoustic correction of classroom in historical buildings. They installed additional absorbent materials to surface of vertical wall behind the teacher's position and ceiling surface in different models and numerical values obtained for objective parameters of sound were compared [14]. Trematerra, Antonio and Iannace produced a sound absorbing material from giant reeds and then they researched to acoustic effect of them on a wall in a classroom. They measured to objective parameters of sound with and without the absorbing materials in the classroom [15]. The placement of absorbing surfaces is very important in reverberation rooms that sound absorption coefficients are measured [16], [17]. So Alessandro and Pispola investigated about effect to sound absorption coefficient of placement of the sound absorbing panels of a noise barrier in a reverberation room. They generally found different sound absorption coefficients at same frequencies [17]. By using ODEON v 6.5, Wang and Rathsam modelled a rectangular room with 10 different absorption schemes. In these schemes, the area of mirrored reflective surfaces, the average sound absorption coefficients and the standard deviation of sound absorption were changed. It was found that the sensitivity of the model room to the scattering coefficient (SC) was affected most by the mirrored reflective surfaces [18]. Bistafa and Bradley carried out a study in a classroom where they changed the number and positions of sound absorbers. They found out that the reverberation time depends on both the number and positions of sound absorbers [19].

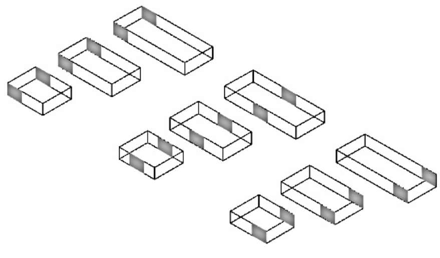
The dimensions of a room and the areas that are sound absorbing materials installed on surfaces in the room is very important in terms of room acoustic. In previous studies generally were researched the effects of relocation sound absorbing materials, change of sound absorbing materials amount and whether or not sound absorbing materials on surfaces to the numerical values of objective parameters of sound. In addition to these researches, in some studies were researched effects on objective parameters of sound of scattering coefficients of surfaces. In this study, both relocations of sound absorbing materials and the change of sound absorbing materials amount in rooms having three different dimensions were researched in terms of effect on the objective parameters of sound.

II. Method

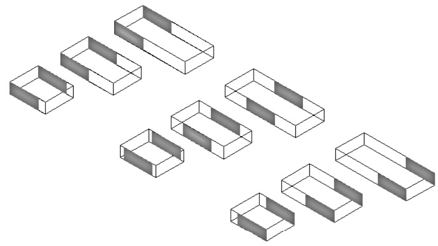
The aim of this study was to determine the effects of the replacement of sound absorbers on the side walls of the rooms of different sizes on the objective parameters of sound. For this reason, first of all in this study, three different models were prepared for three different rooms. The rooms having the same width and height dimensions had different lengths. All the rooms were 8 m. width and 3 m. height. Length dimensions of the rooms were 10 m., 15 m. and 20 m. respectively. The absorber materials were placed on the walls of the rooms with three different ways. Sound absorber materials were selected two different dimensions. The dimensions were 4 m. and 8 m. long with 3 m. height (Fig. 1). Except for sound absorber materials on the walls, ground, walls and ceiling surfaces of the rooms had different materials but each surface had same material. All materials on the surface were selected from the Odeon 10 material library (Table II).

No changes were made on the sizes of the front and back walls in any models. In addition, no changes were made in the materials on the wall and ceiling surfaces. In all models, the sound absorbers were placed on the side wall surfaces in three different ways. In the first, the sound absorbers were placed on the part of the surface of the side wall where it meets the front wall. In the second, the sound absorbers were placed on the centre part of the side walls. And in the third, the sound absorbers were placed on the part of the surface of the side wall where it meets the back wall. This is the same for all three model rooms that have varying sizes. Keeping their placement positions constant, the sound absorbers were placed on the surfaces in two different sizes. In the first, the area of the sound absorbers is 12 m^2, and in the second 24 m^2 (Fig. 1).

No audience was placed in the room in order not to cause any changes in the room size-sound absorber ratio. Acoustic plaster was chosen as the sound absorber. These materials were placed on the surfaces of side walls and three different evaluations were made for each of the six model which amounts to a total of 18 different evaluations. Table shows sound absorption coefficients of using materials on wall surfaces. The materials were selected from Odeon Version 10 Material Library.



(a)



(b)

Fig. 1 Settlement on surfaces of sound absorber materials (a) Sound absorber material, 12 m^2 (b) Sound absorber material, 24 m^2: Sound Absorber 1. The position of the sound absorber in the middle of the wall Sound Absorber 2. The position of the sound absorber at the back of the wall

TABLE II
SOUND ABSORPTION COEFFICIENT OF USING MATERIALS ON THE WALL SURFACES

		Frequencies (Hz)							
Surfaces	Materials	63	125	250	500	1000	2000	4000	8000
Walls	Painted plaster surface (4002)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Ceiling	Gypsumboard, 2 layers, total 32 mm (4045)	0.28	0.28	0.12	0.10	0.17	0.13	0.09	0.09
Floor	Linoleum or vinyl stuck to concrete (6000)	0.02	0.02	0.02	0.03	0.04	004	0.05	0.05
Sound Absorbers	Acoustic plaster (4038)	0.15	0.15	0.25	0.40	0.55	0.60	0.60	0.60

The procedures used in this study are respectively as follows:

First, 3D models were prepared. These models were entered into ODEON v10. Sound source was placed in the same place for all models (Source: 1.50, 0.00, 1.50). The positions of the receivers were determined according to the model size.

- For Form 1;
  Receiver 1: (4.00, 0.00, 1.20), Receiver 2: (5.00, 2.00, 1.20), Receiver 3: (6.00, -2.00, 1.20), Receiver 4: (8.00, 1.00, 1.20)
- For Form 2;
  Receiver 1: (6.00, 0.00, 1.20), Receiver 2: (7.50, 2.00, 1.20), Receiver 3: (9.00, -2.00, 1.20), Receiver 4: (12.00, 1.00, 1.20)
- For Form 3;
  Receiver 1: (8.00, 0.00, 1.20), Receiver 2: (10.00, 2.00, 1.20), Receiver 3: (12.00, -2.00, 1.20), Receiver 4: (16.00, 1.00, 1.20).

The sound source was 1,5 m across the front wall on the long axis in the models. In all models, the values of the objective parameters of sound were obtained with four different receivers that were all at the same positions (Fig. 2). The receivers were placed in the front, middle and at the back of the hall.

In order to check whether there was any sound leak, some general materials were applied on the surfaces of the models. After securing that there was no sound leak, the materials were applied on the surfaces. The general (global) reverberation time that was to be evaluated as data in the room acoustics calculation parameters was obtained. Assignments were made for the values of the calculation parameters. The program was run and the values for the objective parameters of sound were obtained. In order to obtain the objective parameters of sound in the space, the recommendations in the ODEON v10 manual were taken into consideration in the calculation parameters of the software.

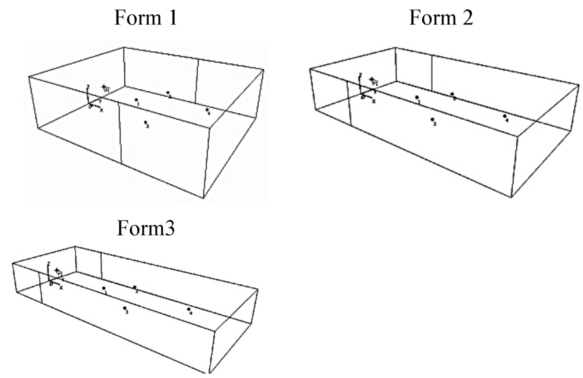


Fig. 2 Settlement of sound source and receivers

Lambert was chosen as sound diffuser, and 707 Hz was chosen as the key diffraction frequency. The number of beams used for control was chosen as 30.000, maximum number of reflection as 2.000, impulse response length as 1000 ms, and transition order as 2. Sound scattering coefficients for the materials that were to be used on the surfaces of the models were also chosen in line with the recommendations in the ODEON v10 manual. The models in which sound absorbers were placed at the end of the long walls where the long walls meet the front wall were taken as the basic values (Fig. 1). The model detail is important in order to get accurate results regarding the objective parameters of sound. Models with too many details may not give accurate results [20]. For this reason, a plain form and surface were preferred in this study.

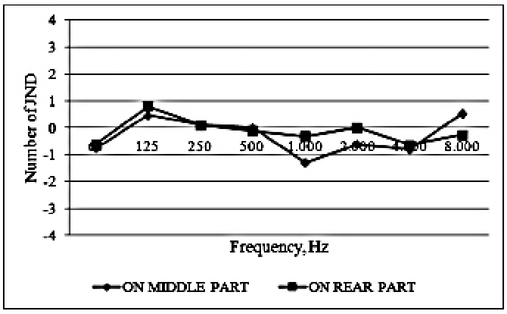
III. Results

This section presents effects of the change of length of the room and relocation of sound absorbers on the objective parameters of sound by making comparisons among the jnd values that were obtained through numerical data.

Sound absorbers of the same surface areas were placed on the front, middle and back walls of three spaces of different sizes and values of objective parameters of sound were obtained. The values obtained from the middle and back parts were compared with the values that were obtained from the front parts as reference values, and in this way the effects of the relocation of sound absorbers on the objective parameters of sound were determined. These differences were obtained for EDT, T_{30}, C_{80} and D_{50} values.

Except at the 500 frequency in Form 3, no significant differences were obtained in the values when the sound absorber surface area doubled for the same forms. In general, the differences in Forms 2 and 3 were more significant for both Sound Absorbers 1 and 2. For both Sound Absorber 1 and Sound Absorber 2, the differences at both low and high frequencies in Form 1 were more significant compared to the mid frequency region. The most significant difference was obtained in the mid part of Form 3 for Sound Absorber 2. The biggest difference is at 500 Hz frequency in the mid part of Form 3 (Fig. 3). On the whole, compared to the basic value there is a decrease in the EDT values in all forms.

No significant differences were obtained in the EDT values for the three forms.



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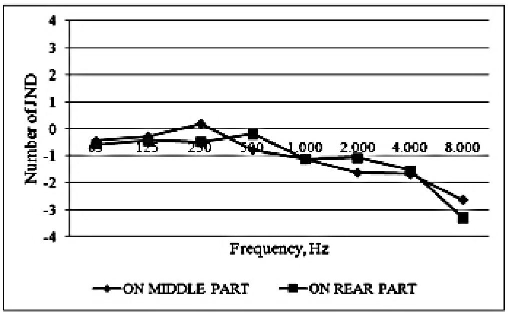

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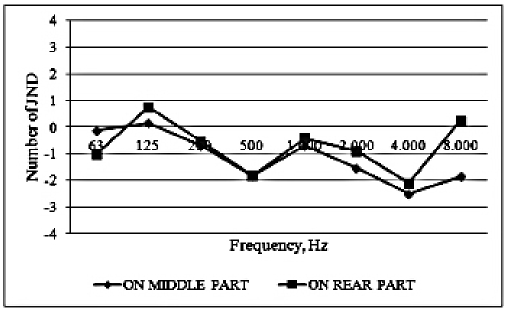
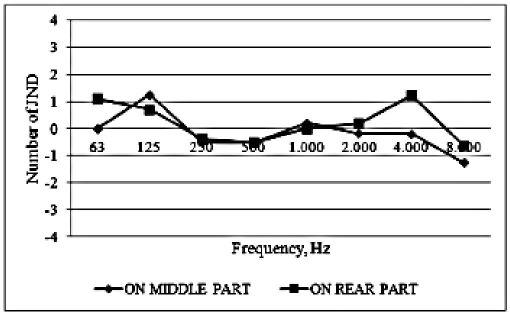


Form 3
For Receiver 1 - Sound Absorber 1



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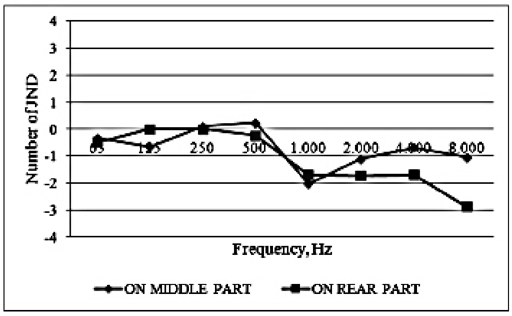

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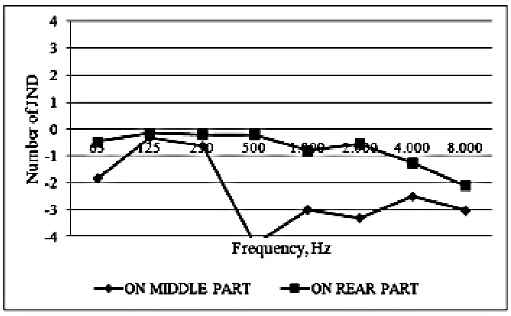
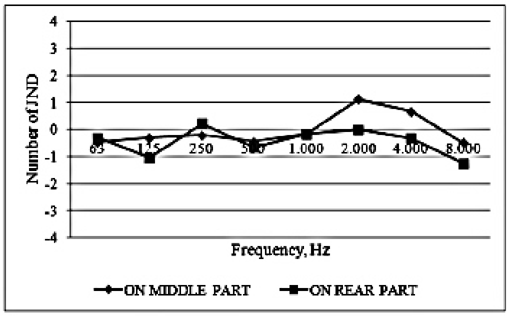


Form 3
For Receiver 1- Sound Absorber 2

Fig. 3 The locations of the sound absorbers in two different surface areas and the difference values obtained for EDT at Receiver 1

At the Receiver 2 point, the differences in EDT were not significant for Sound Absorbers 1 and 2. For Sound Absorber 2 position, the most significant differences were obtained at the mid frequency area in Form 2. When the differences were compared for the sound absorbers placed in the middle and back parts, differences based on frequency and form were obtained. The maximum difference was obtained at 1000 Hz frequency at the back part of the space in Form 2. In general, for both Sound Absorber 1 and Sound Absorber 2, there is a decrease in the values in Forms 2 and 3, while in Form 1 the values differ by being based on frequency (Fig. 4).



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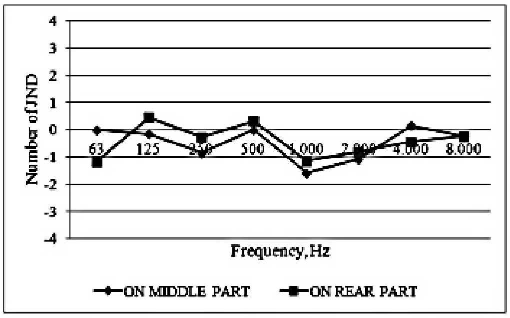

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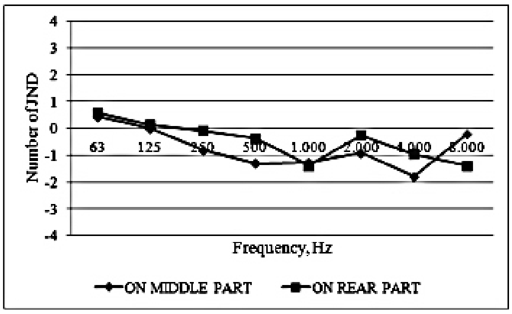

Form 3
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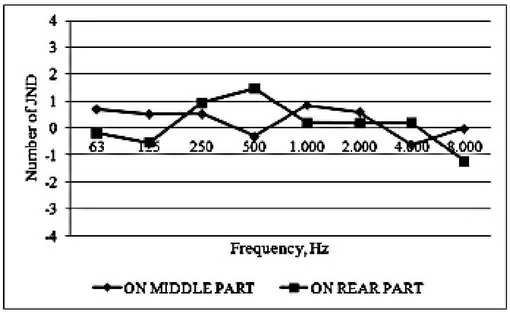

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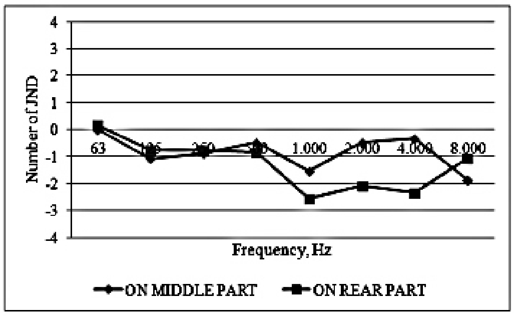

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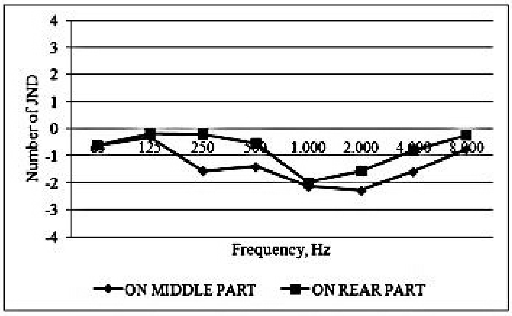
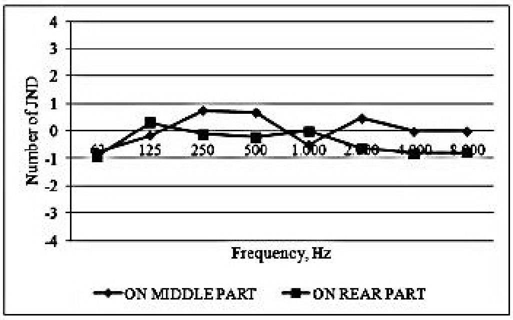


Form 3
For Receiver 2- Sound Absorber 2

Fig. 4 The locations of the sound absorbers in two different surface areas and the difference values obtained for EDT at Receiver 2

At the Receiver 3 point, the differences in EDT were not significant for Sound Absorbers 1 and 2. The most significant differences in Forms 2 and 3 were obtained for Sound Absorber 2. While in form 2 the differences were significant at the middle and high frequencies, in Form 3 they were significant at middle frequency. Again, while the differences in Form 2 were significant at the low frequency in the middle part, they were significant at the middle and high frequencies at the back part of the space. On the other hand, the magnitude of difference in Form 3 varies depending on the frequency. When compared with the basic value, it was found that there were mostly decreases in the EDT values while there were increases in some forms and frequencies (Fig. 5).



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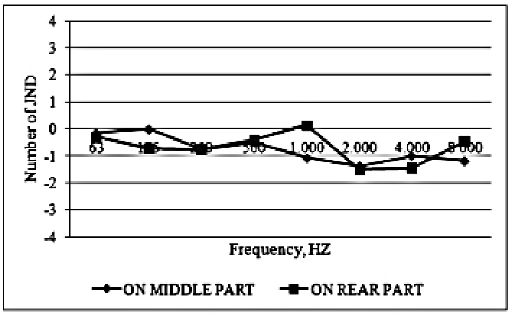

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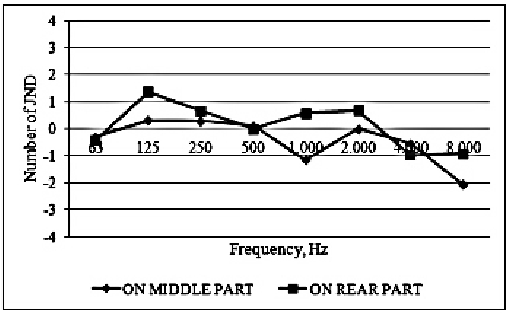
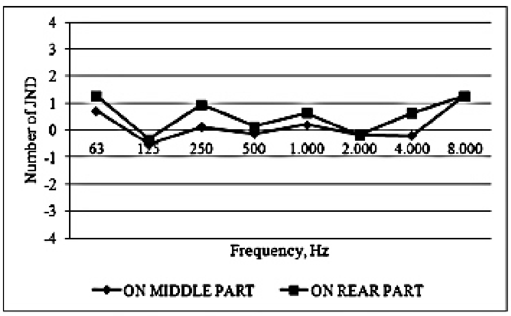


Form 3

For Receiver 3- Sound Absorber 1



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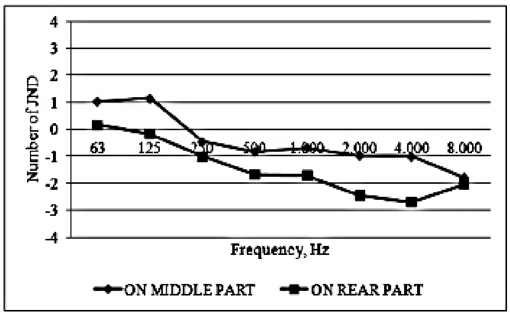

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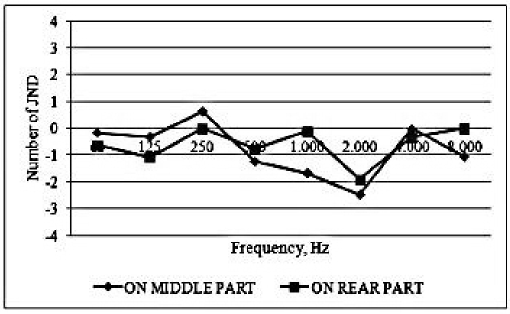
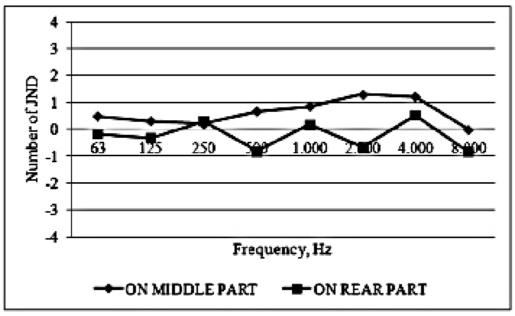


Form 3

For Receiver 3- Sound Absorber 2

Fig. 5 The locations of the sound absorbers in two different surface areas and the difference values obtained for EDT at Receiver 3 point

In general, the most significant differences for Sound Absorber 2 were obtained in Form 3. The differences in the middle and back parts vary depending on the frequency. At all receiver points, the significance of EDT differences was found to be below the level of noticeability. In general, the differences in the values for Sound Absorber 1 and Sound Absorber 2 vary depending on the frequency and form (Fig. 6).



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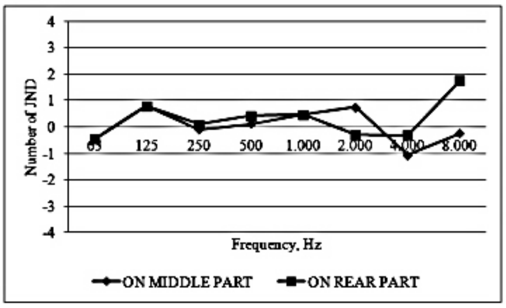

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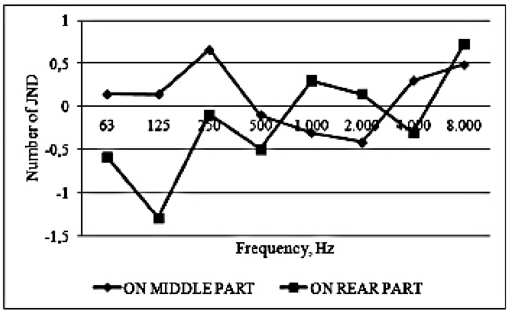

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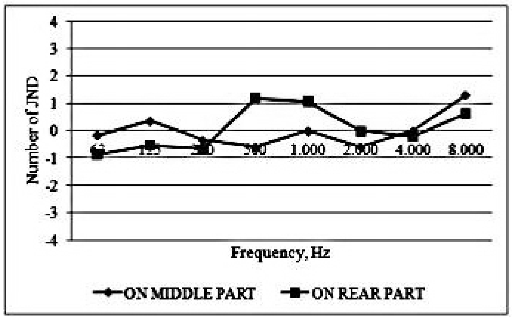
For Receiver 4- Sound Absorber 1



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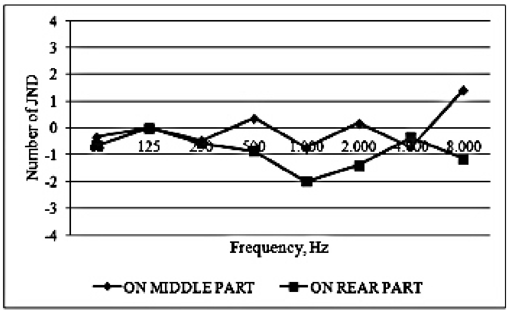

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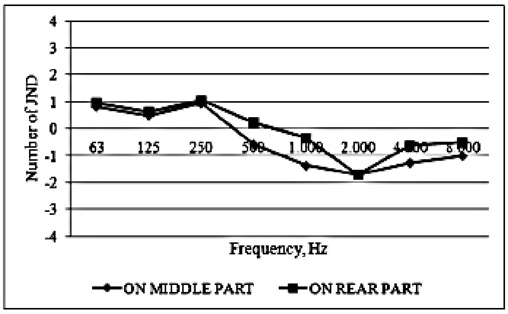
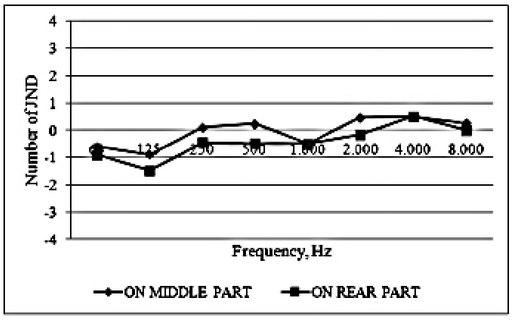


Form 3
For Receiver 4- Sound Absorber 2

Fig. 6 The locations of the sound absorbers in two different surface areas and the difference values obtained for EDT at Receiver 4

At all receiver points, the significance of the T_{30} differences was found to be below the level of noticeability. The most significant differences for Sound Absorber 1 were obtained in Form 2, and for Sound Absorber 2 in Form 3. The most significant difference was obtained in Form 2 at 125 Hz frequency. When the sound absorbers in the middle and at the back of the space are considered, the differences vary depending on the frequency and form (Fig. 7).



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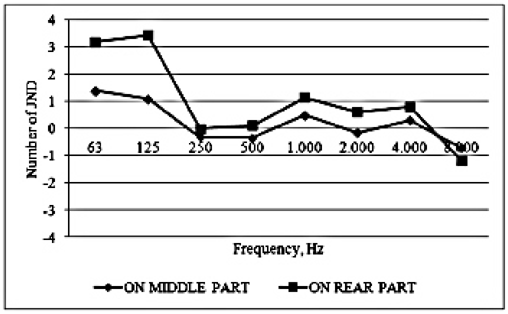

Form 2

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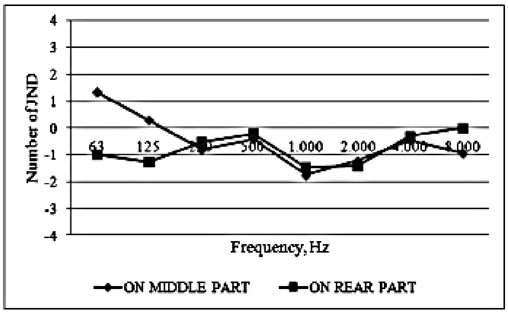

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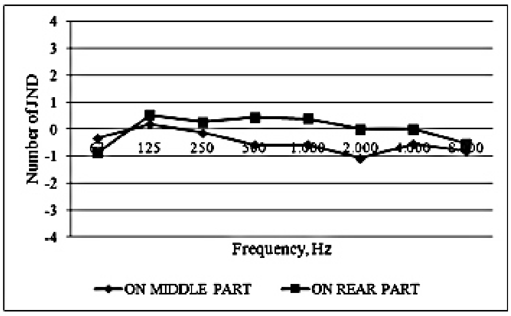
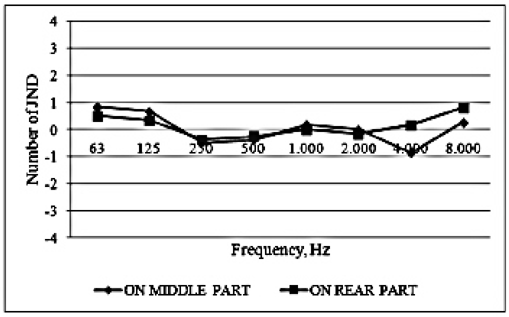
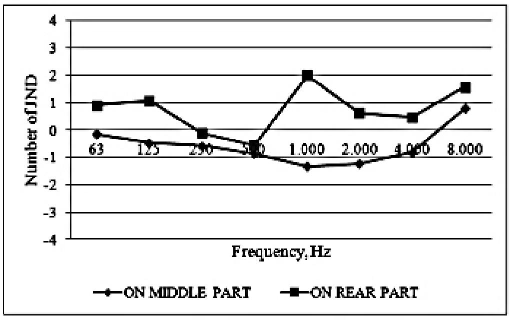


Form 1



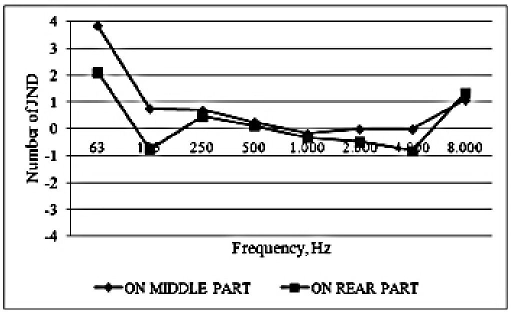
Form 2



Form 3
For Receiver 1- Sound Absorber 2

Fig. 7 The locations of the sound absorbers in two different surface areas and the difference values obtained for T_{30} at Receiver 1

The significance of T_{30} differences for Receiver 2 in all forms is also below the level of noticeability. The most significant differences were obtained for Sound Absorber 1 in Forms 1, 2 and 3 especially at low frequencies. The most significant difference was obtained at 63 Hz frequency in Form 1. When the positions of the sound absorbers in the space are taken into consideration, the differences vary according to the frequency and form (Fig. 8).



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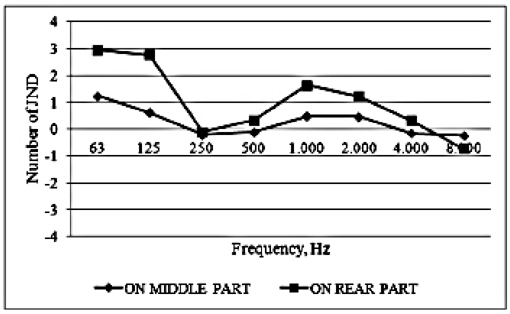

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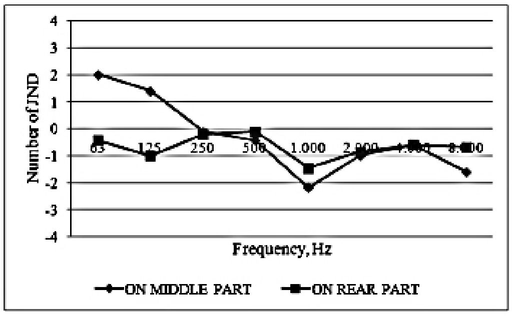
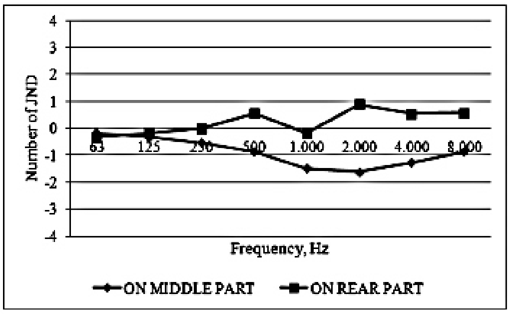


Form 3
For Receiver 2- Sound Absorber 1



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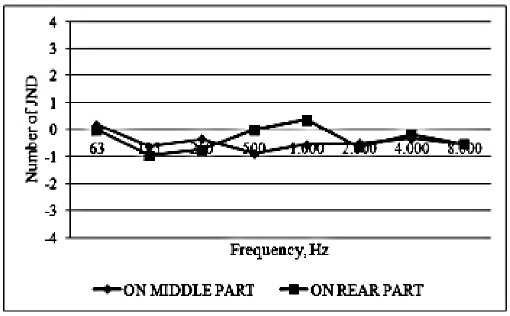

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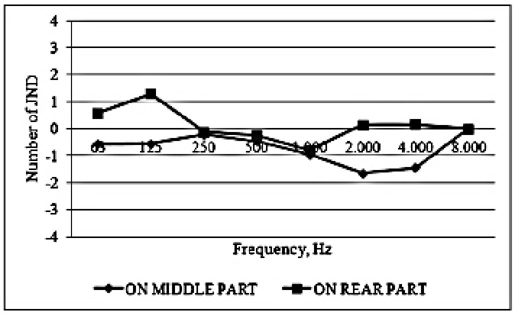
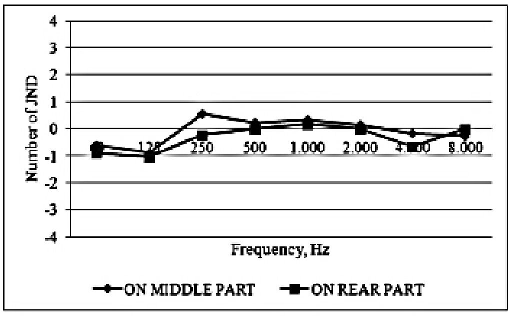


Form 3

For Receiver 2- Sound Absorber 2

Fig. 8 The locations of the sound absorbers in two different surface areas and the difference values obtained for T_{30} at Receiver 2

In all forms, the T_{30} differences for Receiver 3 are below the level of noticeability. The most significant differences for Sound Absorber 1 were obtained in Forms 2 and 3. The most significant differences were obtained at 63 Hz frequency in Form 2. In general, when the positions of the sound absorbers are considered, while the differences for Sound Absorber 1 in Forms 2 and 3 were significant at the back, in others the differences varied according to frequency and form (Fig. 9).



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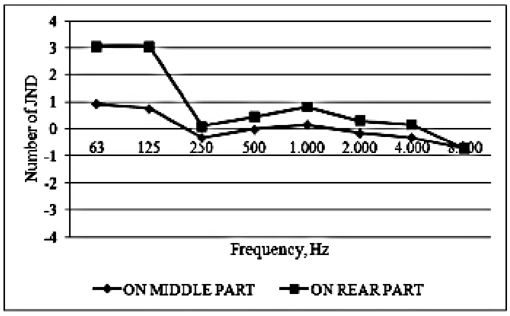

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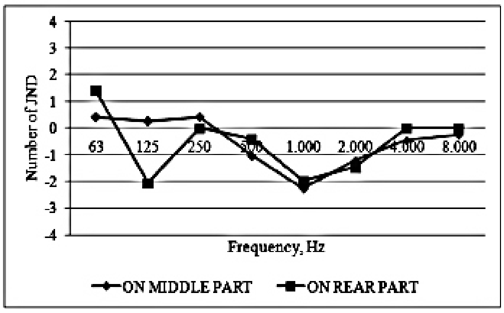
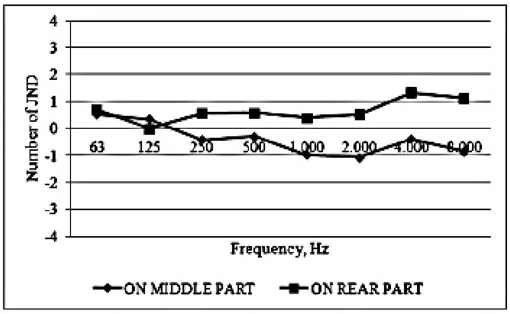


Form 3

For Receiver 3- Sound Absorber 1



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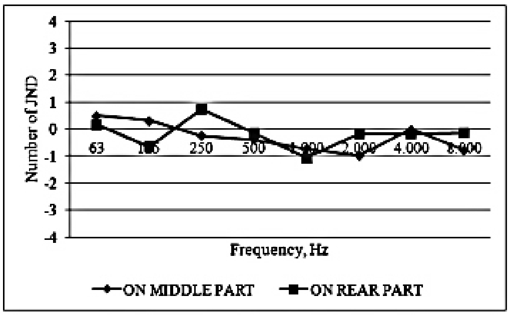

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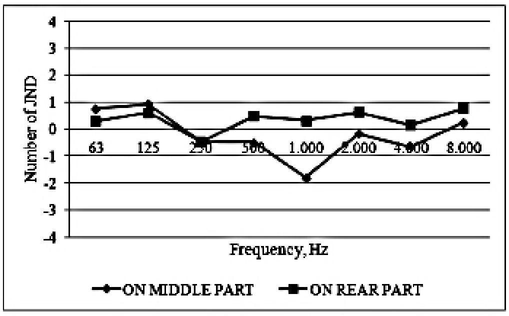
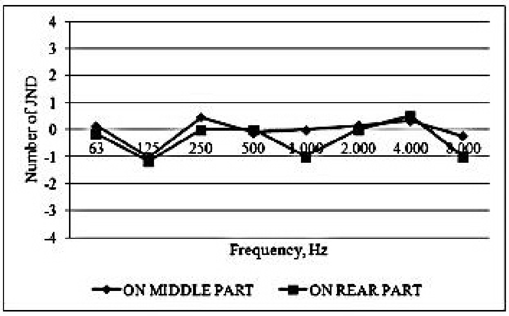


Form 3
For Receiver 3- Sound Absorber 2

Fig. 9 The locations of the sound absorbers in two different surface areas and the difference values obtained for T_{30} at Receiver 3

For Receiver 4, the magnitude of T_{30} differences in all forms were found to be below the level of noticeability. The most significant differences for Sound Absorber 1 were obtained in Form 2 at low frequency, and at middle frequency in Form 3. The most significant difference for Sound Absorber 1 was obtained at the 1000 Hz frequency in Form 3. In general, when the positions of the sound absorbers are considered, for Sound Absorber 1 the differences at the back of the space are more significant in all forms while for Sound Absorber 2 the differences vary according to the frequency (Fig. 10).



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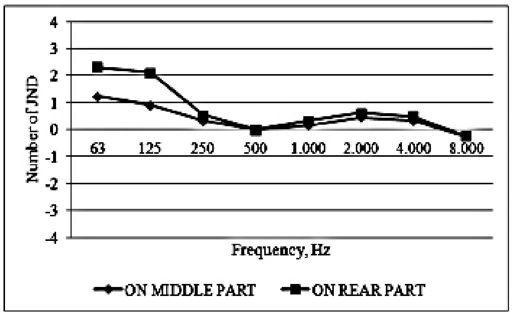

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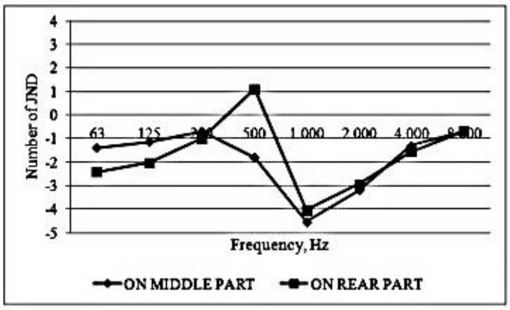
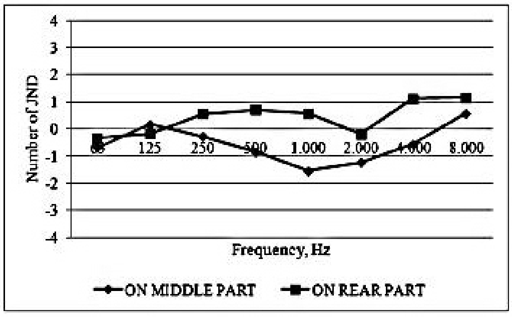


Form 3
For Receiver 4- Sound Absorber 1



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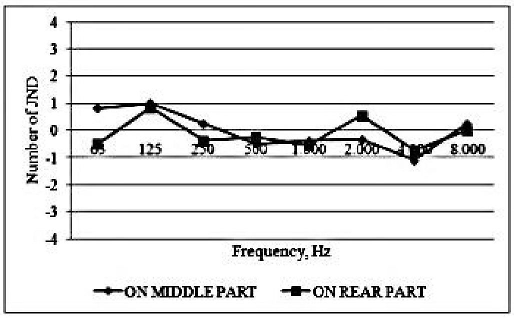

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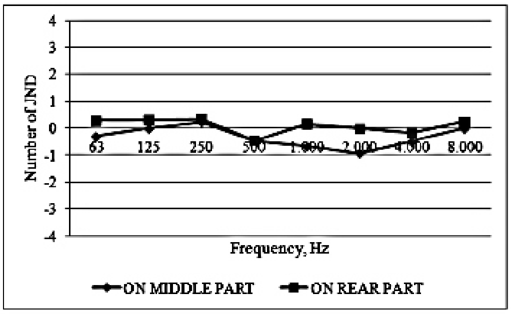
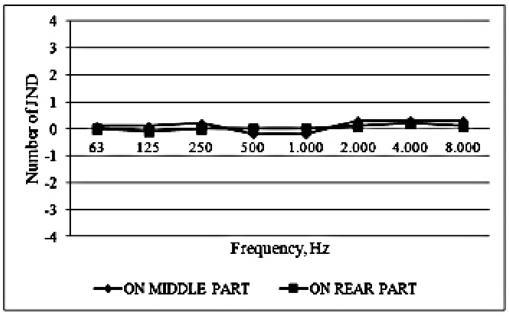


Form 3
For Receiver 4- Sound Absorber 2

Fig. 10 The locations of the sound absorbers in two different surface areas and the difference values obtained for T_{30} at Receiver 4

The magnitude of C_{80} differences for Receiver 1 is generally below the level of noticeability. The most significant differences for Sound Absorber 1 were obtained in Form 2, and for Sound Absorber 2 in Form 3. The most significant difference was obtained at 2000 Hz frequency in Form 2. The differences for Sound Absorber 2 in Form 3 are more noticeable at 1000-4000 Hz frequencies in the middle part of the space. When the sound absorbers in the middle and at the back of the space were considered, the differences were generally found to be more significant in the middle of the space (Fig. 11).



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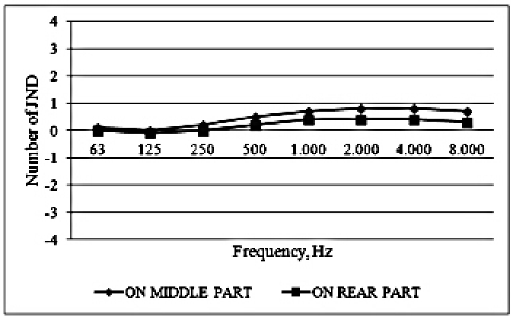

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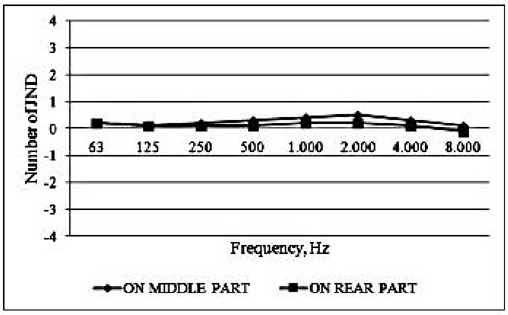
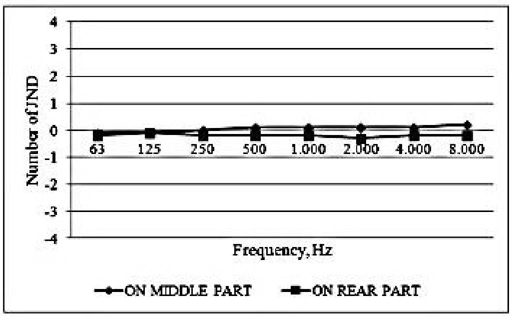


Form 3
For Receiver 1- Sound Absorber 1



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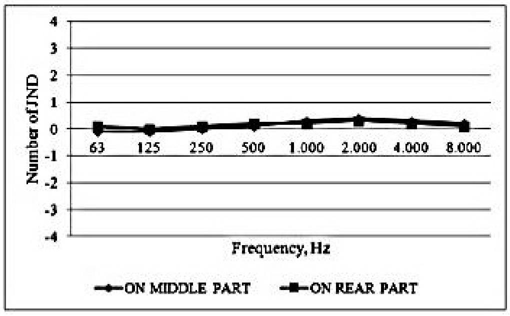

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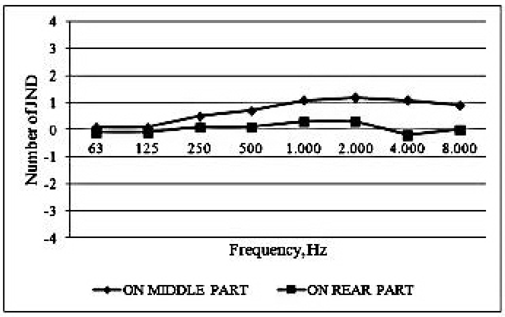

Form 3
For Receiver 1- Sound Absorber 2

Fig. 11 The locations of the sound absorbers in two different surface areas and the difference values obtained for C_{80} at Receiver 1

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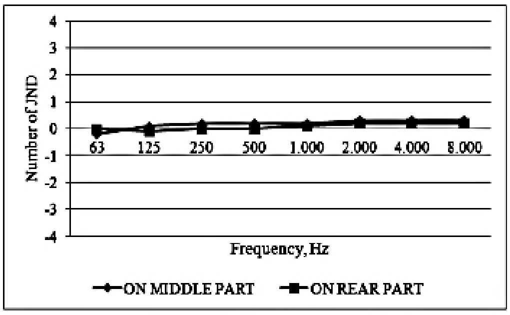
The magnitude of C_{80} differences were also generally below the level of noticeability for Receiver 2. The most significant differences were obtained for Sound Absorber 1 in Forms 2 and 3. The most significant difference was obtained at 2000 Hz frequency in Form 3. The difference for Sound Absorber 2 in Form 3 is noticeable in the middle at 2000 Hz frequency. When the sound absorbers in the middle and at the back of the space were considered, the differences were in general more significant in the middle of the space (Fig. 12).



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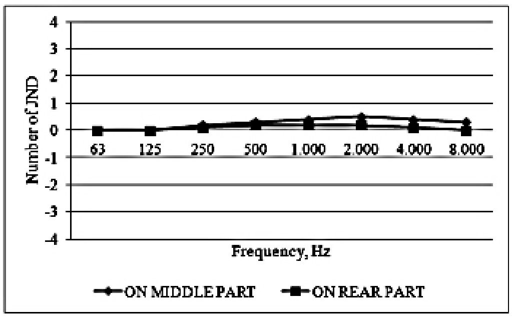

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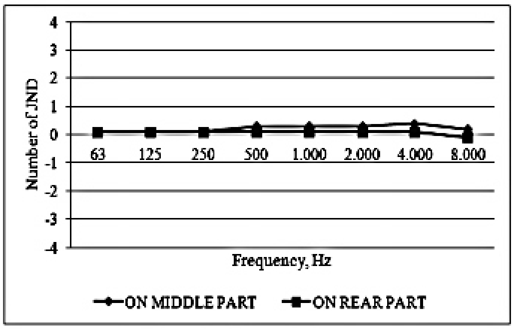
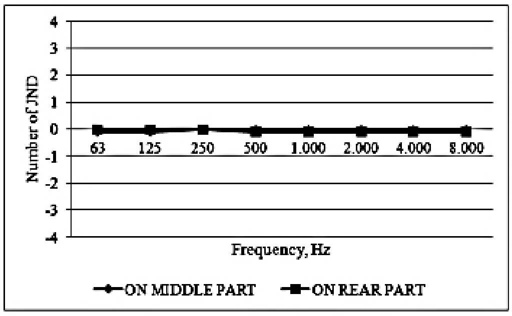


Form 3
For Receiver 2- Sound Absorber 1



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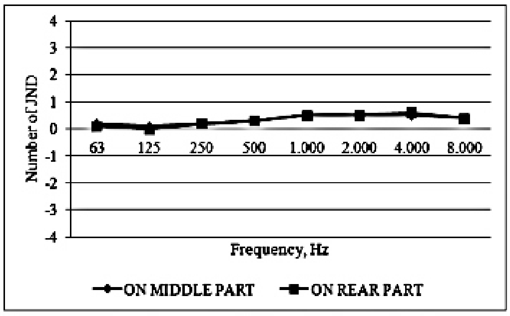

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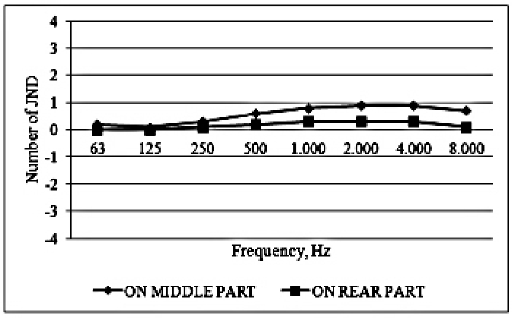
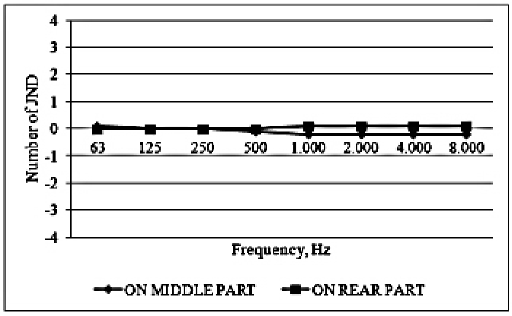


Form 3
For Receiver 2- Sound Absorber 2

Fig. 12 The locations of the sound absorbers in two different surface areas and the difference values obtained for C_{80} at Receiver 2

The significance of C_{80} differences at Receiver 3 are below the level of noticeability in all forms. The most significant differences for Sound Absorber 2 were obtained in Forms 2 and 3. The most significant differences in these forms were obtained at middle and high frequencies. When the sound absorbers in the middle and at the back of the space are considered, the differences showed variety depending on the form (Fig. 13).



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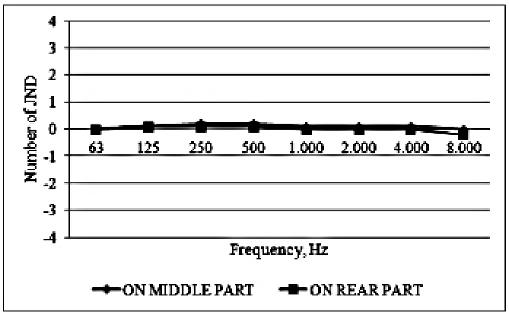

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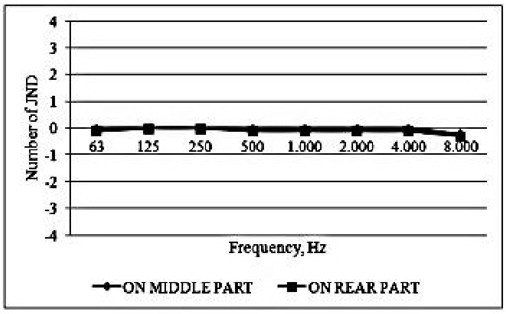
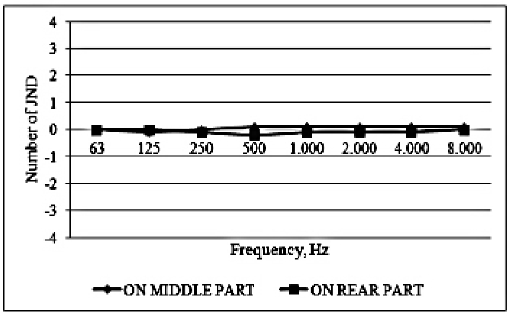


Form 3
For Receiver 3- Sound Absorber 1



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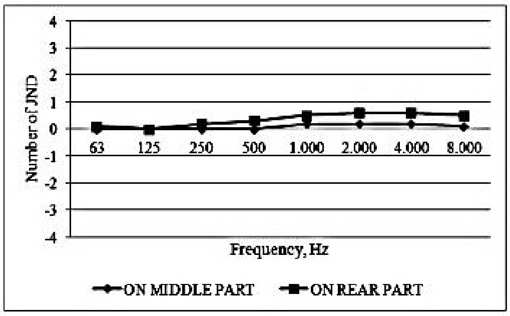

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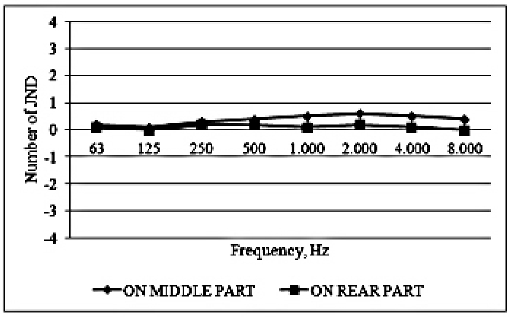
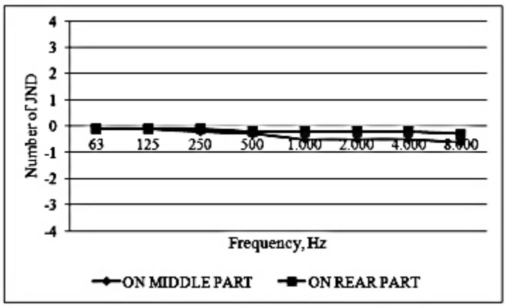


Form 3
For Receiver 3- Sound Absorber 2

Fig. 13 The locations of the sound absorbers in two different surface areas and the difference values obtained for C_{80} at Receiver 3

The significance of the differences for Receiver 4 were also found to be below the level noticeability. The most significant differences for Sound Absorber 1 were obtained in Forms 1 and 3 while for Sound Absorber 2 in Form 2. Significant differences were obtained at middle and high frequencies. When the sound absorbers in the middle and at the back of the space were considered, it was found that the differences for Sound Absorber 1 varied depending on the form while for Sound Absorber 2 the differences were generally found to be significant at the back of the space (Fig. 14).



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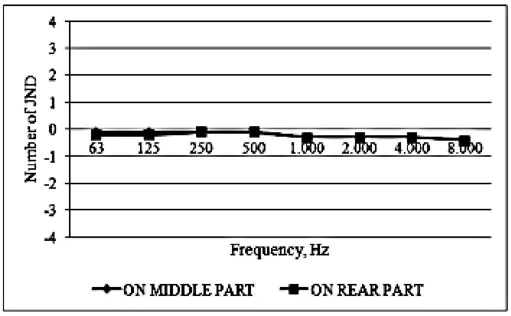

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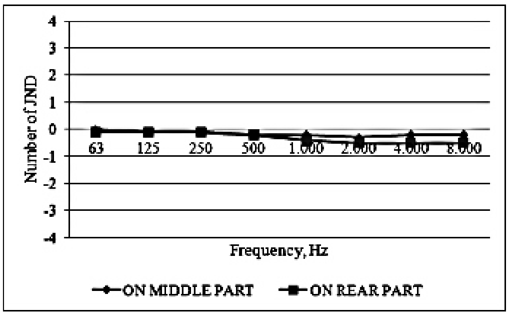
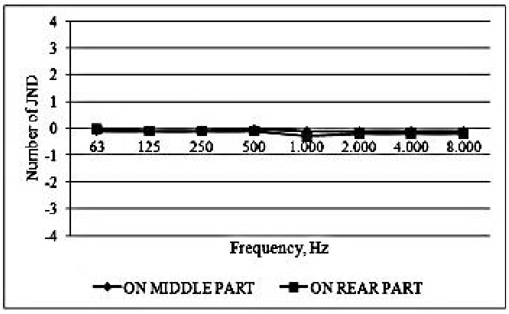


Form 3
For Receiver 4- Sound Absorber 1



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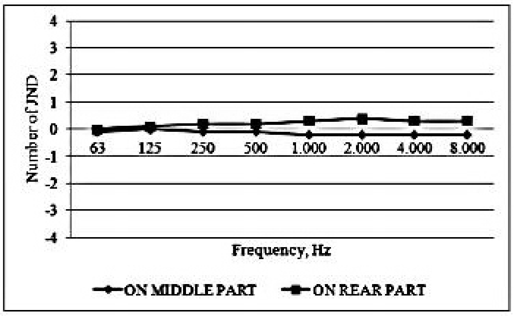

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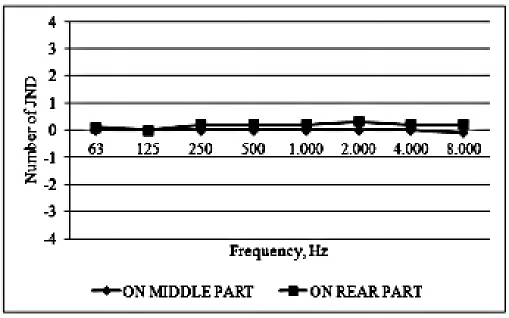
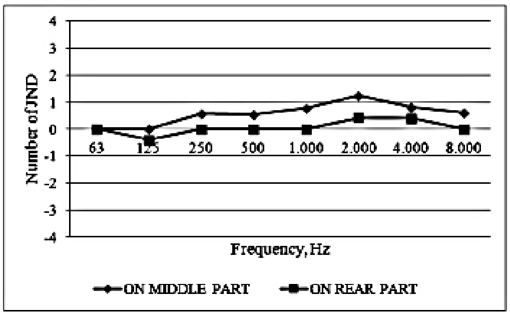


Form 3
For Receiver 4- Sound Absorber 2

Fig. 14 The locations of the sound absorbers in two different surface areas and the difference values obtained for C_{80} at Receiver 4 point

The magnitude of the D_{50} differences for Receiver 1 is below the level of noticeability in all forms. The most significant differences for Sound Absorber 1 were obtained in the middle in Form 2 and at middle and high frequencies; for Sound Absorber 2 in the middle and at the back in Form 3 and at middle and high frequencies. When the sound absorbers in the middle and at the back of the space were considered, it was found that the differences varied according to the form (Fig. 15).



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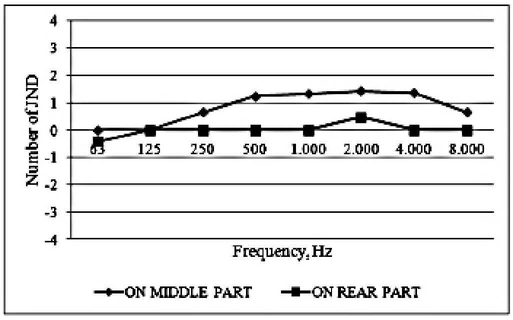

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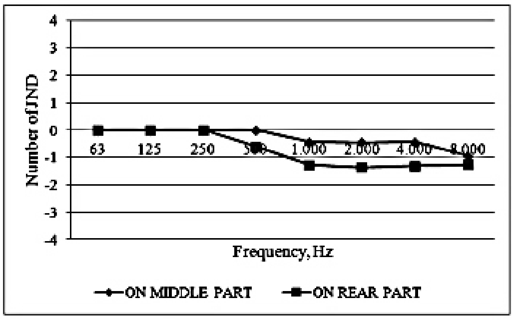
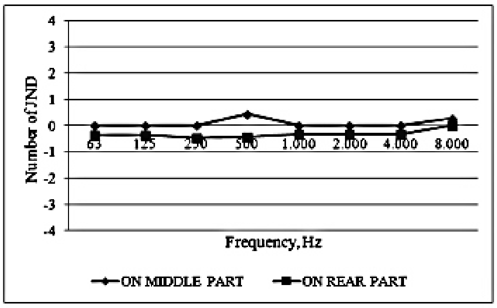


Form 3
For Receiver 1- Sound Absorber 1



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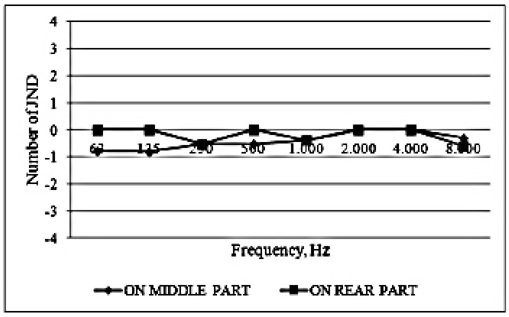

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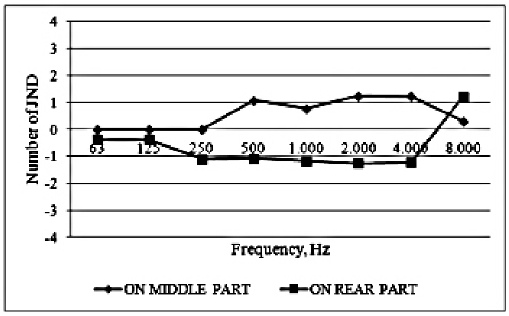
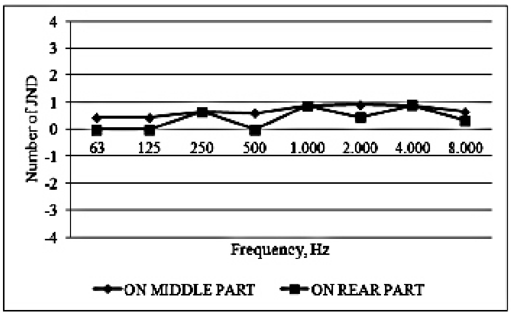


Form 3
For Receiver 1- Sound Absorber 2

Fig. 15 The locations of the sound absorbers in two different surface areas and the difference values obtained for D_{50} at Receiver 1 point

The magnitude of D_{50} differences for Receiver 2 was also found to be below the level of noticeability. The most significant differences for Sound Absorber 1 were obtained in the middle of the space in Form 2, and for Sound Absorber 2 in the middle of the space in Form 3. When the sound absorbers in the middle and at the back of the space were considered, the differences are in general more significant in the middle of the space (Fig. 16).



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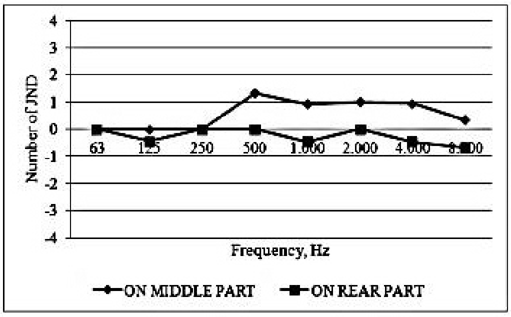

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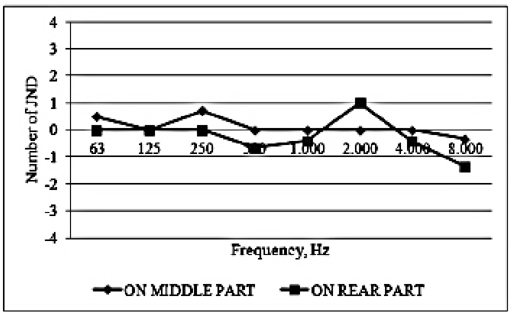

Form 3
For Receiver 2- Sound Absorber 1

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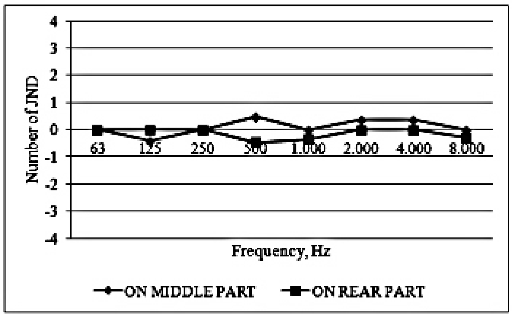
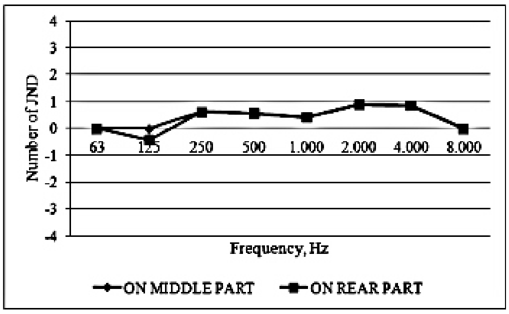
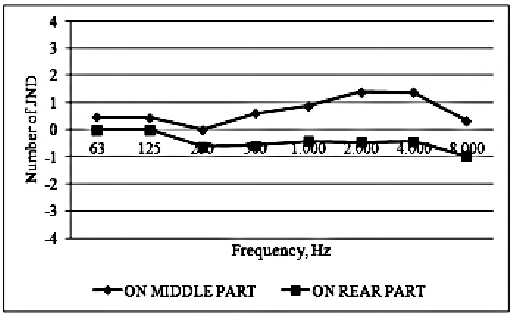


Form 1



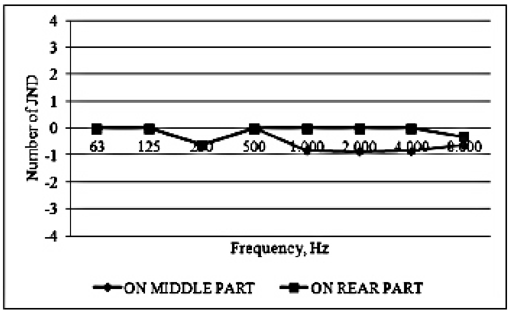
Form 2



Form 3
For Receiver 2- Sound Absorber 2

Fig. 16 The locations of the sound absorbers in two different surface areas and the difference values obtained for D_{50} at Receiver 2 point

The magnitude of D_{50} differences in Receiver 3 were found to be below the level of noticeability in all forms. The most significant differences for Sound Absorber 1 were obtained in the middle of the space in Form 3 and for Sound Absorber 2 in the middle of the space in Form 3 and especially at middle frequencies. When the sound absorbers in the middle and at the back of the space were considered, it was found that the differences for Sound Absorbers 1 and 2 varied according to form (Fig. 17).



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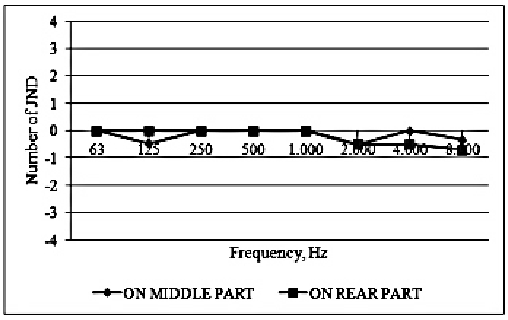

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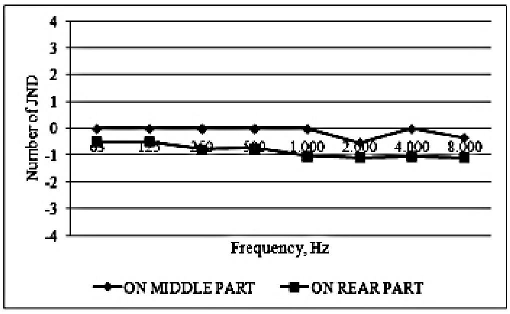
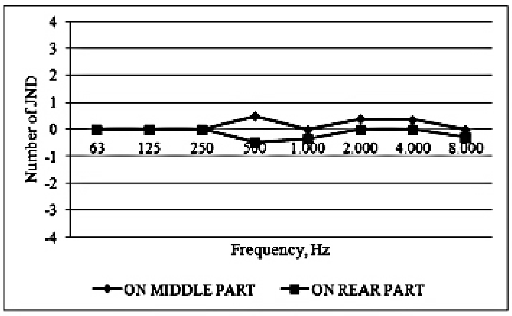
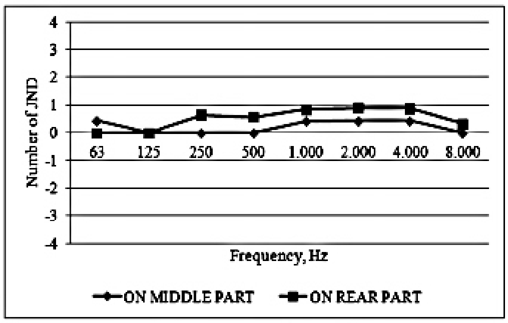


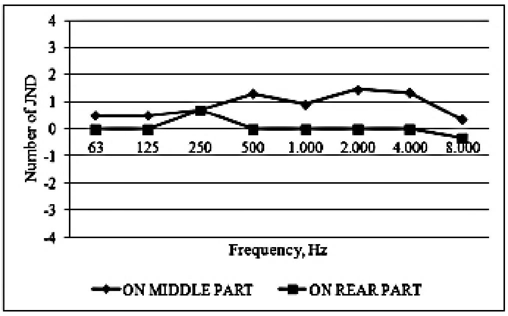
Form 3
For Receiver 3- Sound Absorber 1



Form 1



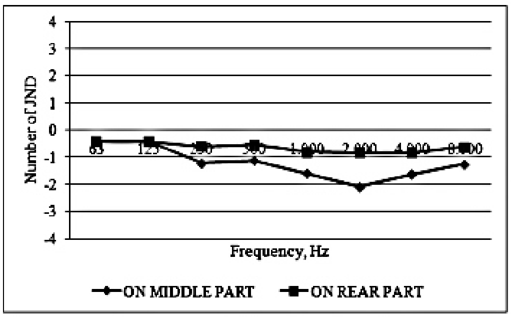
Form 2



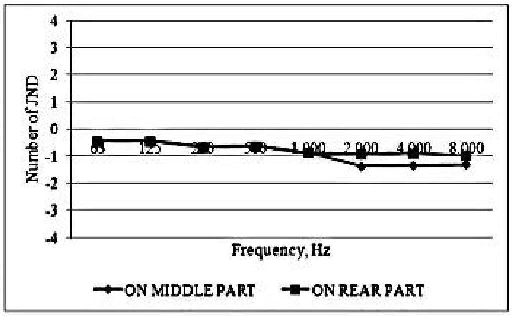
Form 3
For Receiver 3- Sound Absorber 2

Fig. 17 The locations of the sound absorbers in two different surface areas and the difference values obtained for D_{50} at Receiver 3 point

The significance of the D_{50} differences in Receiver 4 were also found to be below the level of noticeability. The most significant differences for Sound Absorber 1 were obtained in the middle of the space in Form 1, and for Sound Absorber 2 they were obtained as varying according to frequency in Form 2. The difference at 2000 frequency is more significant than those in other frequencies. When the sound absorbers in the middle and at the back of the space were considered, the differences in the middle for Sound Absorber 1 were more while in Sound Absorber 2 the differences varied according to frequency and form (Fig. 18).



Form 1



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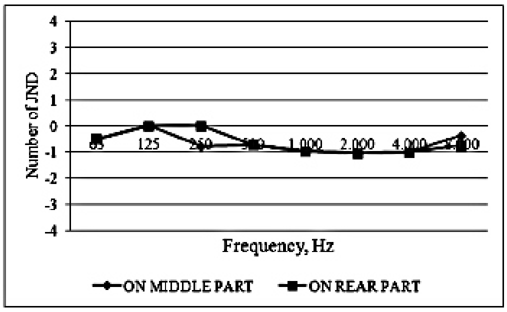
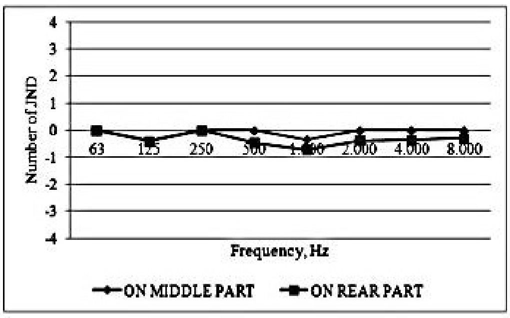
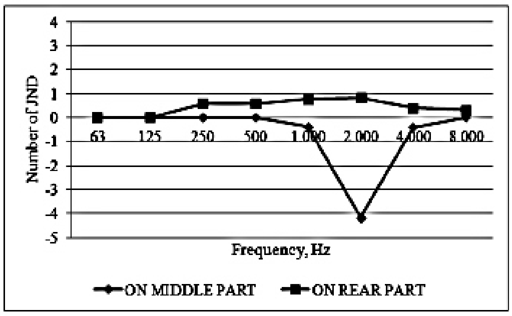


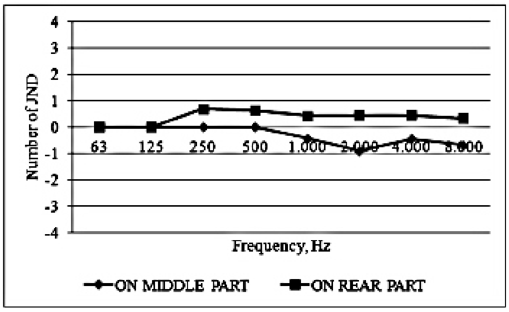
Form 3
For Receiver 4- Sound Absorber 1



Form 1



Form 2



Form 3
For Receiver 4- Sound Absorber 2

Fig. 18 The locations of the sound absorbers in two different surface areas and the difference values obtained for D_{50} at Receiver 4 point

In previous studies [12]-[15], [17], relocation and changes of amount of sound absorbing materials have caused to change of objective parameters of sound like this study results. But this study evaluated to change of the different situations in terms of jnd.

IV. Conclusions

This study attempted to determine the effects of the relocation of sound absorbers in a space on the objective parameters of sound according to the basic value. The noticeable difference values for EDT, T_{30} and D_{50} were obtained below the level of jnd. On the other hand, in C_{80}, some noticeable differences were obtained for Sound Absorber 2 in Form 3 at some frequencies. For Sound Absorbers 1 and 2, the differences in the jnd values in general showed variety according to frequency. When the room forms were considered, it was found that the differences in the objective parameters of sound varied according to frequency and type of objective parameters. In next studies, this method may be applied on halls having high volume as theatre and concert halls. Also, this method may be applied at more different configurations with sound absorber and diffuser panels.

References

[1] ISO 3382, *Acoustics – Measurements of the Reverberation Time of Rooms with Reference to Other Parameters*, 1997.
[2] J. H. Rindel, "Room acoustic modelling techniques: a comparison of a scale model and a computer model for a new opera theatre", *Proceedings of the International Symposium on Room Acoustics,* Melbourne, 2010.
[3] C. L. Christensen, *"Odeon Room Acoustic Program. Version 10, User Manual"*. Ed. Scion DTU, Denmark, 2009.
[4] D.T. Bradley and L. M. Wang, "Comparison of measured and computer-modeled objective parameters for an existing coupled volume concert hall", *Building Acoustics*, 14-2, pp. 79-90, 2007.
[5] A.Vural, *Acoustical Evaluation of Four Concert Halls in Istanbul.* MSc. Thesis, Istanbul Technical University, Turkey, 2009.
[6] V. L. Jordan, "Acoustical criteria for auditoriums and their relation to model techniques", *Journal of the Acoustical Society of America,* 47-2: pp. 408-412, 1970.
[7] H. Kuttruff, *Room Acoustics*. E & FN Spon. New York, 2000.
[8] L. M. Wang, J. Rathsam, and S. Ryherd, "Interactions of model detail level and scattering coefficients in room acoustic computer simulation", *Architectural Engineering Architectural Engineering - Faculty Publications*, University of Nebraska – Lincoln, Nebraska, USA, 2004.
[9] A.K. Klosak, and A. C. Gade, "Relationship between room shape and acoustics of rectangular concert halls", *Euro Noise, Acoustics'08 Paris*, Paris, 2008, pp.2163-2168.
[10] M. Lisa, J. H. Rindel, and C. L. Christensen, "Predicting the acoustics of ancient open-air theatres: the importance of calculation methods and geometrical details", *Joint Baltic-Nordic Acoustics Meeting*, Mariehamn, 2004.
[11] E. Green, M. Barron, and D. Thompson, "The effect of scattering surfaces in rectangular concert halls: a scale model analysis", *Proceedings of the Institute of Acoustics*, 34 Pt.2., 2011.
[12] E. Nilsson, "Room acoustic measures for classrooms", *Inter Noise 2010*, Lisbon, Portugal, 2010.
[13] T. Sakuma, and J. Guo, "Effect of absorbing panels on acoustic quality in small rectangular meeting rooms", I*nter Noise 2013*, Innsbruck, Austria. 2013.
[14] G. Iannace, P. Trematerra, and A. Qandil, "The acoustic correction of classrooms in historical buildings with numerical simulation", *AIA-DAGA 2013*, Merano, 2013, pp. 204-207.
[15] A.Trematerra, M. Antonio, and G. Iannace, "Use of green material for acoustic correction inside rooms", *Journal of Sustainable Architecture and Civil Engineering*, 3(4), 2013, pp.33-38.
[16] A.C. C. Warnock, "Some practical aspects of absorption measurements in reverberation rooms", *The Journal of the Acoustical Society of America*, 74 (5), 1983, pp. 1422-1432.
[17] F. D'Alessandro, and G. Pispola, "Sound Absorption properties of sustainable fibrous materials in an enhanced reverberation rooms", *Inter Noise 2005 Environmental Noise Control*, Brasil, 2005.
[18] L. M. Wang, and J. Rathsam, "The influence of absorption factors on the sensitivity of a virtual room's sound field to scattering coefficients", *Applied Acoustics*, 69, 2008, pp. 1249-1257.
[19] S. R. Bistafa, and J. S. Bradley, "Predicting reverberation times in a simulated classroom", *Journal of the Acoustical Society of America*, 108-4, 2000, pp. 1721-1731.
[20] S. Siltanen, T. Lokki, L. Savioja, "Geometry reduction in room acoustics modeling", *Proceedings of the Institute of Acoustics*, 28, 2006, pp. 409-416.