

An Acoustical Evaluation of the Ankara University Medical School Faculty Members' Dining Hall

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Abstract
Today, finish surface materials with hard, unruffled, or smooth surfaces are preferred in the tiling, walls, and ceilings of restaurants and dining halls because of their hygienic and easy-cleaning characteristics. In this context, in restaurants and dining halls that have sound-reflecting surfacesare also classified as reverberant rooms where talking sounds are added to the background noise level; thus, the noise level in the setting increases gradually, and speech intelligibility is affected unfavorably. In the context of this study, the pre-assessment of the dining hall of Ankara University Medical School faculty members was completed by using measurements, simulations, and estimation methods; because the appropriate acoustic conditions that comply with regulations, international standards, and suggestions in the literature were not met, suggestions were developed for acoustic treatment. Because of feasibility issues, improvements were implemented only on the walls, which was one option among the several suggested, and then acoustic measurements were repeated. Following the application, improvements in acoustic conditions occurred within the dining hall, and the characteristics of oral communication was improved to an acceptable level according to the literature; however, it was also revealed that a further level of improvement of oral communication could be achieved by implementation of the suggested sound-absorbing suspended ceiling.

Keywords: Acoustics, Building Acoustic, Room Acoustic, Dining Hall, Restaurant.

1. INTRODUCTION

Today, the low level of verbal communication and speech intelligibility in restaurants and dining halls is a common acoustic problem; the reasons that that this problem occurs, as suggested in the literature and by international standards or regulations, are summarized below.

- Longer reverberation in restaurants and dining halls compared to the reverberation time that is appropriate for speech [1].
- The formation of the Lombard effect as defined in the literature and by recognized standards (TS EN ISO 9921), i.e., the gradual increasing of the ambient noise level due to the vocal efforts of the speakers [1, 2, 3, 4],

- The number of users exceeding the proposed acoustical volume capacity as described in the literature (total capacity) [1].

2. METHOD

In the scope of this study, before the application:

- Measurements were taken of the external traffic noise levels and the background noise level, the current situation was evaluated according to the acoustic conditions suggested in the regulations, and analyses were made of the outer structure components that enable environmental noise control. For the outer structure components' analyses, the INSUL (*V 6.4)* building acoustic simulation program was used [5].
- The current situation assessment of the room acoustics of the dining hall was completed by making measurements of the reverberation time (T_{30}), the equivalent continuous A-weighted sound pressure level (L_{Aeq}), and an A-weighted sound pressure level measurement of speech at a distance of one meter ($L_{S,A,1m}$), and suggestions were developed for correcting the acoustic conditions and improving speech intelligibility as suggested in the literature. For the room acoustic analyses, the ODEON (*V10.02 Combined*) room acoustic simulation program was used [6].
- The ambient noise level ($L_{N,A}$)and the sufficient level of verbal communication in the dining hall was estimated by using the calculation method "acoustic capacity," and the maximum capacity for which the dining hall can provide service was revealed.

Following the application:

- Acoustic measurements were taken in the dining hall again to determine the acoustic conditions after the acoustic treatment;
- The effect of the sound absorbing surface application involving only the wall surfaces on the quality of verbal communication and acoustical capacity of the dining hall was revealed.

3. FINDINGS AND DISCUSSION

3.1. Analysis and Assessment of Ambient Noise and Building Acoustic Control

For noise control in the dining hall of the faculty members of Ankara University Medical School, environmental noise level measurements were taken in accordance with TS 9315 ISO 1996-1 and TS ISO 1996-2 standards by noise-level measurement equipment (Reten Electronic Sound Level Meter, Type 2) [7,8].

Results of the environmental noise level measurements:

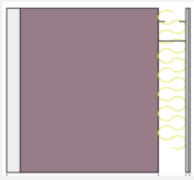
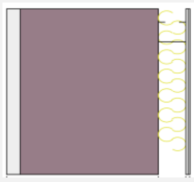
- **LAeq** **:** The equivalent continuous sound pressure level(A-weighted) was determined as 55,5 dB(A).

Table 3.1.The sound insulation performance suggested for the outer construction component of the building according to DIN 4109 standard [9]:

Environmental Noise Level Interval - LAeq[9]	Sound Reduction Index of Outer Construction Components - Rw,res[9]
Up to 55dB(A)	30 dB
56 dB(A) – 60 dB(A)	30 dB

Analyses and assessment of the sound insulation performance of the noise control of the outer construction component surrounding the dining hall were made according to the following acoustic parameters. The assessment of the sound insulation performance of the outer construction components indicated in architectural application projects according to the international standards is shown in Table 3.2.

Table 3.2.Analysis of sound insulation performances of the construction components

Outer Construction Component (Outer wall + window/door)			
CURRENT SITUATION			
Material Information	**Construction Component Detail**	**Optimum Value**	**Analysis Result and Assessment**
• Acrylic based covering containing silicon additive (1,5 mm) • Surface plaster with cement base • Expanded polystyrene heat insulation plate (5 cm) • Hollow concrete block (25 cm) • Gypsum plaster (satin) • Plastic Paint	 **Side wall (Outer wall-1)** **Wall surface area: 30,3 m^2** **Glass surface area: 29,5 m^2**	**$R_{w,res} \geq 30$ dB [9]**	**39 (-2; -6)** **$R_{w,res}(C; C_{tr})$** **APPROPRIATE**
• Acrylic based covering containing silicon additive (1,5mm) • Ex Surface plaster with cement base • Expanded polystyrene heat insulation plate (5 cm) • Hollow concrete block (25 cm) • Gypsum plaster (satin) • Plastic Paint	 **Front wall (Outer wall-2)** **Wall surface area: 38,4 m^2** **Glass surface area: 19,4 m^2**	**$R_{w,res} \geq 30$ dB [9]**	**41 (-2; -6)** **$R_{w,res}(C; C_{tr})$** **APPROPRIATE**

3.2. Analysis and Assessment of Room Acoustic Control

Before Treatment

In this section of the research, the acoustic conditions were evaluated as to whether they met the international standards and acoustic parameters suggested in the literature for the function of the place; this was done by using wall and suspended ceiling materials in the dining hall architectural application projects [10,11,14,15,16,17,18].

The following are the goals for the room acoustics of the dining hall:

- Providing the reverberation time needed for volume function,
- Improvement of speech intelligibility within the volume, and
- Prevention of acoustic problems such as echoing.

Analysis and assessment of the acoustic conditions within the dining hall for room acoustic were made based on the acoustic parameters summarized below.

- **T_{30}** : Reverberation Time (s)
- **EDT** : Early Decay Time (s)
- **STI** : Speech Transmission Index
- **D_{50}** : Definition

In the dining hall, which has approximately 880 m^3 of air volume, the reverberation time needed for speech should be in the interval of0,56 s $\leq$ Tmid $\leq$ 0,84 s [10,11].

The background noise level measurements taken in the dining hall were compared to the Environmental Noise Assessment and Management Regulation effective in Turkey; the ANSI standards are given in Table 3.3.

Table 3.3.Background noise level

Environmental Noise Assessment and Management Regulation [12]		ABD Standard (ANSI) [13]	Measured background noise level	
Closed Window LAeq dB(A)	Open Window LAeq dB(A)		Closed Window LAeq dB(A)	Open Window LAeq dB(A)
35	45	NCB 38-43 [~ 46-53 dB(A)]	32 APPROPRIATE	38 APPROPRIATE

Table 3.4.Analysis results of the dining hall in terms of room acoustics and developed suggestions

Room Acoustics parameters	Optimum Values	Current situation Analysis	Suggestion1*	Suggestion2** (*Optimum*)	Suggestion3***
Tmid Reverberation Time, s	0,56≤$T_{30,mid}$ ≤ 0,84 (500 Hz - 1000 Hz) [10, 11]	0,99 sn NOT APPROPRIATE (Simulation analysis) 1,04 sn NOT APPROPRIATE (measurement)	0,68 s APPROPRIATE	0,74 s APPROPRIATE	0,66s APPROPRIATE
EDT Early Decay Time	EDT <T_{30} (500 Hz - 1000 Hz) [14]	1,02 s NOT APPROPRIATE	0,56 s APPROPRIATE	0,53 s APPROPRIATE	0,50 s APPROPRIATE
STI Speech Transmission Index	0,75 < Very good < 1,00 0,60 < good < 0,75 0,45 < mediu < 0,60 0,30 < weak < 0,45 0,00 < bad < 0,30 [15]	0,61 (medium-good)	0,72 (good)	0,73 (good-very good)	0,73 (good-very good)
D50 Definition	D50 > 0,50 for all frequencies [16,17,18]	125Hz 0,42	0,63	0,72	0,70
		250 Hz 0,45	0,74	0,76	0,77
		500 Hz 0,52	0,74	0,78	0,79
		1000 Hz 0,58	0,78	0,79	0,80
		2000 Hz 0,60	0,75	0,76	0,77
		4000 Hz 0,61	0,76	0,73	0,74

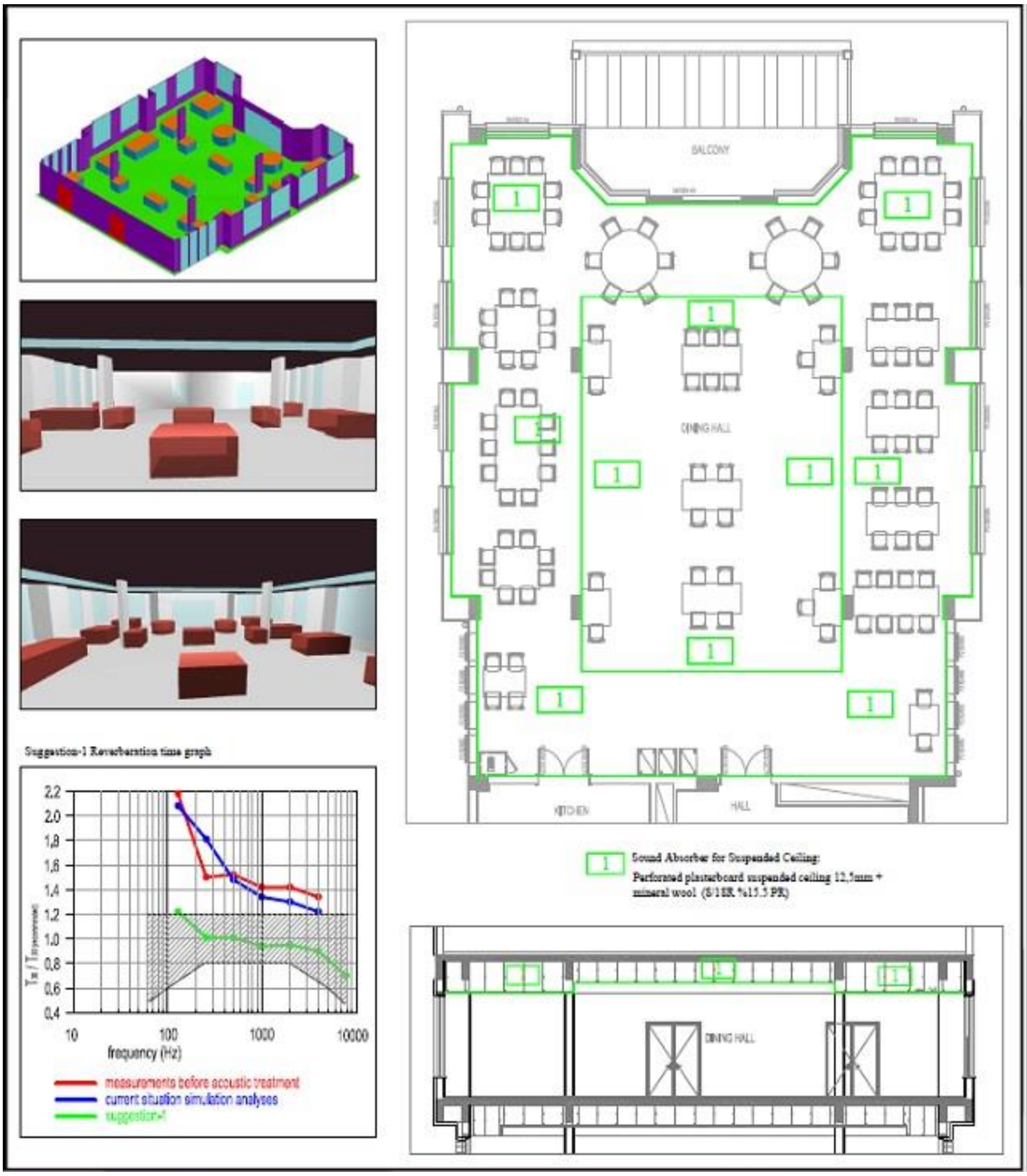
***Suggestion 1; For the ceiling, pool and sections remaining out of the pool;**use of perforated plaster board suspended ceiling 12,5 mm + mineral wool (8/18R %15.5 PR)
****Suggestion 2; In the ceiling and pool section;**8 mm MDF/LAM panel (perforated) + Acousticfelt 0.2 mm + 5 cm Rock wool (50 kg/m^3) in the parts remaining out of the pool; the existing plasterboard suspended ceiling,
In the walls;16-22 mm timber cover(grooved) up to 120 cm + Acoustic felt + 5 cm mineral wool, 18 mm MDF/LAM panel from120 cmup to the ceiling (grooved-perforated) + Acoustic felt 0.2 mm + 5 cm Rockwool (150 kg/m^3) usage
*****Suggestion 3**; **In the ceiling at the pool section;** 8 mm MDF/LAM panel (perforated) + Acoustic felt 0.2 mm + 5 cm Rockwool
(50 kg/m^3), in the section remaining out of the pool; 16-22 mm timber cover + Acoustic felt + 5 cm mineral wool,
In the wall;16-22 mm timber cover (grooved) up to 120cm + Acoustic felt + 5 cm mineral wool, 18 mm MDF/LAM panel
(grooved-perforated) from 120 cm up to the ceiling + Acoustic felt 0.2 mm + 5 cm Rockwool (150 kg/m^3) usage

Reverberation time measurements in the dining hall were made according to TS EN ISO 3382-2: April 2009 standard. Floor, wall and suspended ceiling materials suggested in the architectural application projects had primarily sound-reflecting surface characteristics. As a result of the measurements made for the room acoustics of the dining hall, it was observed that the reverberation time was above the values for speech suggested in the literature and accepted standards (Table 3.4). Thus, it was observed that a reverberation time that is longer than the time needed for volume function unfavorably affected other room acoustic parameters for speech intelligibility.

It was suggested that sound-absorbing finish materials should be added or existing materials replaced with the chosen sound reflective finish materials to provide proper acoustic conditions for volume. For this purpose, three different suggestions were made for changes in the suspended ceiling and wall coverings to provide sound absorbing surfaces that would meet the criteria of international standards and the literature (Table 3.4). The materials suggested for use are summarized in Table 3.5.

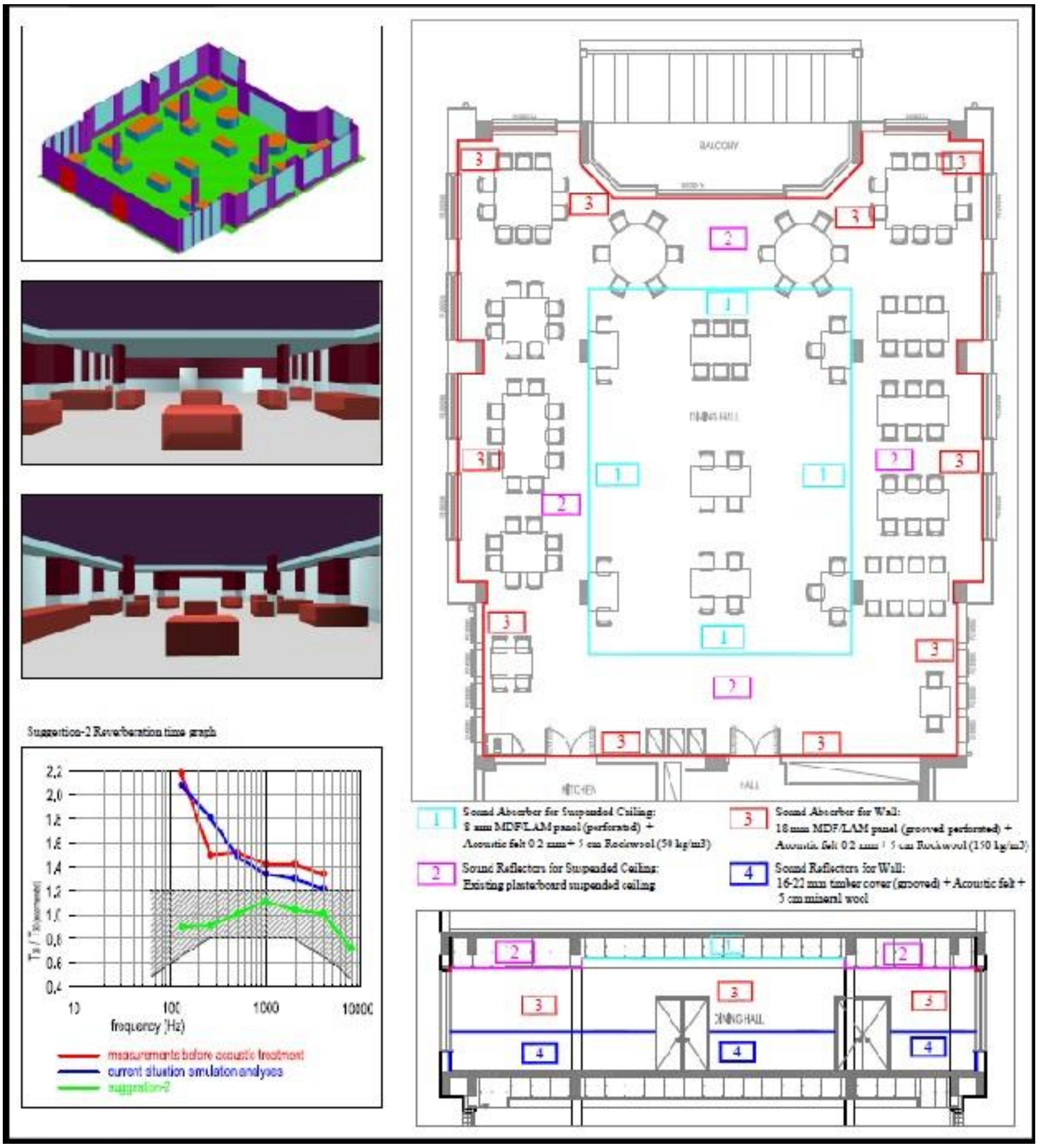
Table 3.5.Sound absorption coefficients of the materials that are suggested to be used

Wooden Wall surface	**18 mm MDF/LAM panel (grooved-perforated) + Acoustic felt 0.2 mm + 5 cm Rockwool (150 kg/m3)**							
	63 Hz	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
	---	0.53	0.68	0.84	0.87	0.82	0.74	---
Suspended wooden ceilings	**8 mm MDF/LAM panel (perforated) + Acoustic felt 0.2 mm + 5 cm Rockwool (50 kg/m^3)**							
	63 Hz	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
	---	0.41	0.58	0.69	0.63	0.54	0.38	---
Plasterboard ceiling	**Perforated plaster board suspended ceiling 12,5 mm + mineral wool(8/18R %15.5 PR)**							
	63 Hz	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
	---	0.55	0.65	0.60	0.70	0.60	0.65	---
Suspended wooden ceilings, Wall surface	**16-22 mm timber cover+ Acoustic felt + 5 cm mineral wool**							
	63 Hz	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
	0.25	0.25	0.15	0.10	0.09	0.08	0.07	0.07



1 For the ceiling pool and sections out of the pool; Perforated plasterboard suspended ceiling 12,5 mm + mineral wool(8/18R %15.5 PR) usage

Figure 3.1.Suggestion-1/ Sound reflective and absorbent surfaces- plan + section and reverberation time graph



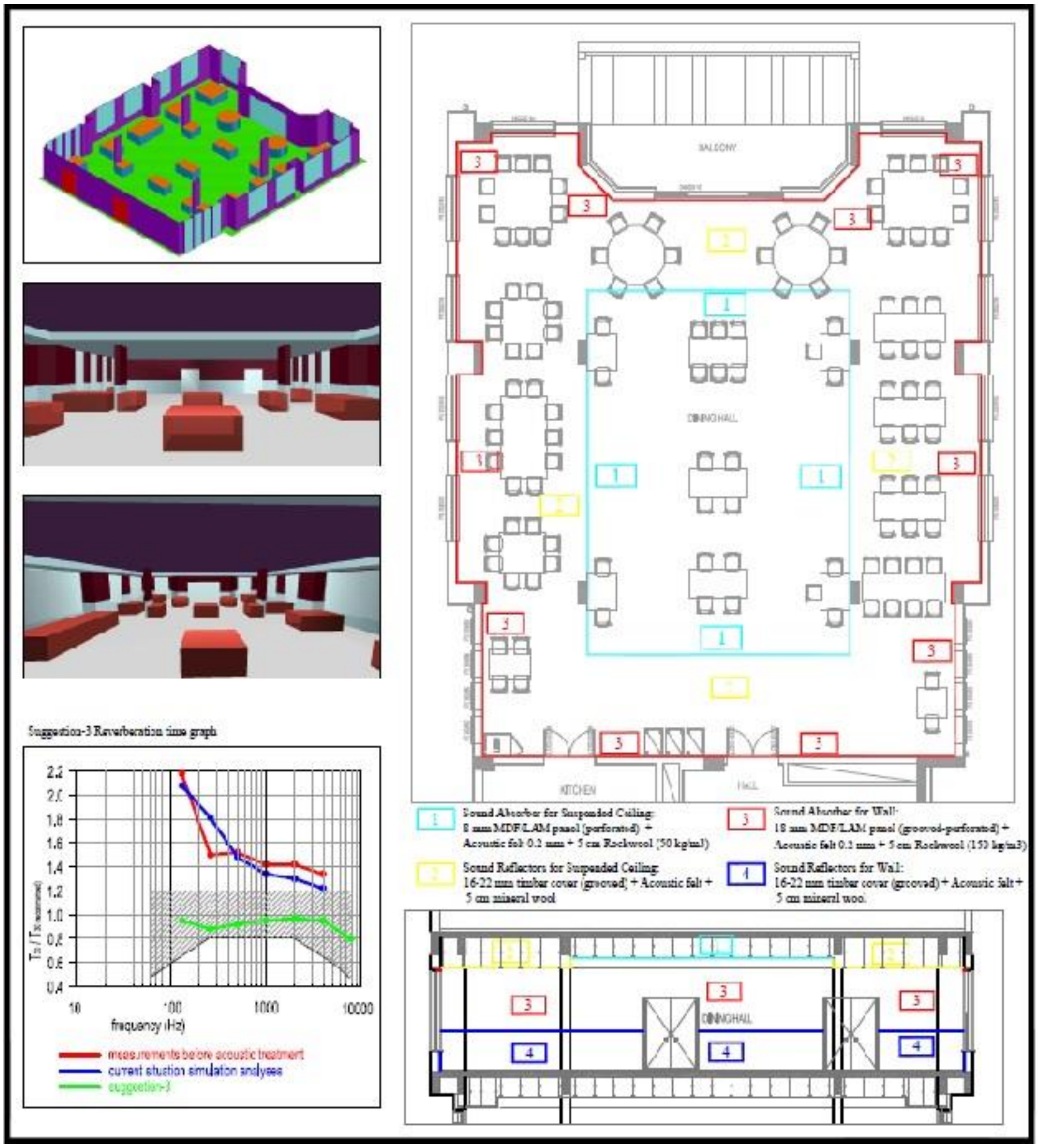
1 *in the pool section;8 mm MDF/LAM panel (perforated) + Acoustic felt 0.2 mm + 5 cm Rockwool (50 kg/m³)*

2 *In the sections out of the pool; existing plasterboard suspended ceiling*

3 *from 120 cmup to the ceiling,18 mm MDF/LAM panel (grooved-perforated) + Acoustic felt 0.2 mm + 5 cm Rockwool (150 kg/m³) usage*

4 *In the wall; up to 120 cm,16-22 mm timber cover (grooved) + Acoustic felt + 5 cm mineral wool*

Figure3.2. Suggestion-2/ Sound reflective and absorbent surfaces- plan + section and reverberation time graph



1 in the pool section; 8 mm MDF/LAM panel (perforated) + Acousticfelt 0.2 mm + 5 cm Rockwool (50 kg/m^3)
2 In the section out of the pool; 16-22 mm timber cover (grooved) + Acoustic felt + 5 cm mineral wool

3 from 120 cm up to the ceiling,18 mm MDF/LAM panel (grooved-perforated) + Acoustic felt 0.2 mm + 5 cm Rockwool (150 kg/m^3) usage
4 In the wall; up to 120 cm,16-22 mm timber cover (grooved) + Acoustic felt + 5 cm mineral wool

Figure 3.3.Suggestion-3/ Sound reflective and absorbent surfaces- plan + section and reverberation time graph

After the application

In the application made after the preliminary study, among the provided suggestions only the improvements for the wall could be made due to feasibility problems with the construction (Figure 3.5). After the application; measurements were repeated in the dining hall, and a new reverberation time was ascertained in order to measure the change in acoustic conditions, specifically volume. The comparisons of the measured pre-application and post-application reverberation timesare given in Table 3.6,Figure 3.4 and Figure 3.5. In addition, the "acoustic capacity," expressing the maximum capacity of the dining hall to give service, was revealed by estimating the ambient noise level with analytic methods and determining whether the verbal communication characteristics were at a sufficient level,

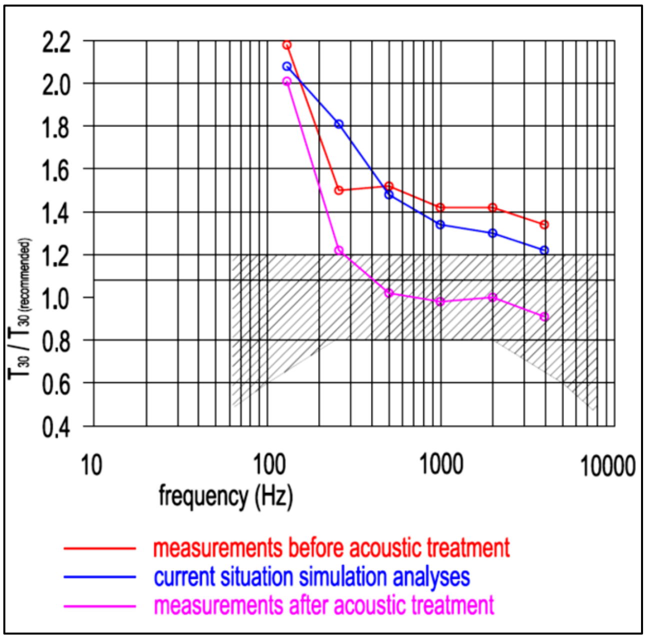


Figure 3.4.After application reverberation time graphic

Table 3.6.Reverberation time before and after the application

T_{30} (s)	***Reverberation Time* – Before application**						
	125 Hz	**250 Hz**	**500 Hz***	**1000 Hz***	**2000 Hz**	**4000 Hz**	$T_{30,mid}$
	1,53	**1,05**	**1,07**	**1,00**	**1,00**	**0,94**	**1,04 s**

T_{30} (s)	***Reverberation Time* – After application**						
	125 Hz	**250 Hz**	**500 Hz***	**1000 Hz***	**2000 Hz**	**4000 Hz**	$T_{30,mid}$
	1,41	**0,86**	**0,72**	**0,69**	**0,76**	**0,64**	**0,71 s**

****$T_{30,mid}$, is estimated based on the reverberation time value at 500 and 1000 Hz.***

a b c d

Figure 3.5.(a-b) Before acoustic treatment, (c-d) After acoustic treatment

Ambient noise level is estimated by the following formula [1]:

$$L_{N,A} = 93 - 20\log\left(\frac{A}{N_S}\right) = 93 - 20\log\left(\frac{A.g}{N}\right) (1)$$

$L_{N,A}$:*ambient noise level*
A :*equivalent absorption area in the room*
N_S :*average number of speaking persons*
N :*total number of people*
g : *average number of people per speaking person*

- **Ambient Noise Level Estimated Before Application**

$$L_{N,A} = 93 - 20\log\left(\frac{85,5}{100}\right) = \mathbf{80,3\ dB(A)}$$

- **Ambient Noise Level Estimated After Application**

$$L_{N,A} = 93 - 20\log\left(\frac{200,5}{100}\right) = \mathbf{73,0\ dB(A)}$$

Table 3.7. Quality of verbal communication before and after the application[1,2]

Quality of verbal communication	SNR dB	$L_{S,A,1m}$ dB(A)	$L_{N,A}$ dB(A)	A / N m^2
• Very good				
	9	56	47	(50 - 65)
• Good				
	3	62	59	(12 - 16)
• Satisfactory				
	0	65	65	(6 - 8)
• Sufficient	(Attribute of oral communication after the application)			
	-3	68	71	(3 - 4)
• Insufficient	(Attribute of oral communication before the application)			
	-9	74	83	(0,3 - 0,6)
• Very bad				

Table 3.8.Acoustic conditions before and after the application

	Air Volume (Volume) (m^3) / Absorption surface area (m^2)	Reverberation Time $T_{30,mid}$ (s): Optimum Values	Reverberation Time: Measured $T_{30,mid}$ (s) *(unoccupied state)*	Capacity (person) / Acoustic capacity (person)	Measured $L_{S,A,1m}$ dB(A) *Time frame 12:30-14:00*	Measured* L_{Aeq} dB(A) *Time frame 12:30-14:00*	Estimated** $L_{N,A}$ dB(A) *(g = 5,0)*
Before the application	V : ~ 880	0,56≤$T_{30,mid}$≤ 0,84 (500 Hz - 1000 Hz) [10, 11]	1,04	~ 100	70,2	77,4	80,3
	A : ~ 85,5			~ 42			
After the application	V : ~ 880		0,71	~ 100	66,4	70,2	73,0
	A : ~ 200,5			~ 62			

During the measurements taken inside the dining hall when the hall was approximately 85% full, ambient noise level values measured are a few dB lower than the values that are estimated by the calculation method.Estimation is made considering hall in a full state (1).

***** Before and after the application, ambient noise level$L_{N,A}$ occurring within the dining hall was calculated by using the calculation method that is suggested in the literature, valid for conditions when the dining hall is completely full.***

4. CONCLUSION AND RECOMMENDATIONS

This study primarily focused on the sound insulation performance analyses of the outer construction components (Insul 6.4), the external traffic noise level and background noise level measurements before the application were made (Table 3.3), and the sound insulation performance of the background noise level in the dining hall; outer structure components were found to comply with international standards ($R_{w,res} \geq 30$ dB) (Table 3.2.).

As a result of the reverberation time measurements for the room acoustic parameters and simulation program analyses (Odeon 10.02), it was determined that the required acoustic conditions were not satisfied. In order to meet the appropriate acoustic conditions, suggestions to improvesdining hall walls and suspended ceiling materials were developed (Table 3.4, Figure 3.1, Figure 3.2, Figure 3.3).

However, among the suggestions that were developed, improvements were made only in the walls of the dining hall due to construction feasibility problems. When the effect on the acoustic conditions within the dining hall of the applied sound absorbing surfaces was measured:

- It was determined that approximately 7,3 dB reduction was achieved in ambient noise level, $L_{N,\,A}$ due to vocal effort level within the dining hall (Table 3.8.).
- An insufficient level of verbal communication quality before the application was raised to the sufficient level suggested in the literature (Table 3.7.).
- The reverberation time ($T_{30,mid}$), around the middle frequencies was 1,04 seconds before the application and was 0,71 seconds after the application; it was determined to be at an appropriate level in a restaurant or dining hall for speech (Table 3.6, Table 3.8).

In conclusion, improvement to the acoustic conditions within the dining hall was achieved after treatment, and the verbal communication quality was improved to a sufficient level as suggested in the literature. Also, the improvement of verbal communication characteristic to a higher level could be achieved by implementation of the sound-absorbing suspended ceiling applications that are included in the developed suggestions (Table 3.4). For improving verbal communication characteristics to a sufficient level, the sound-absorbing surface area located in the suspended ceiling and wall surfaces of the dining hall should be more than 4 m^2 for each user, approximately (Table 3.7). Furthermore, low frequency sound-absorbing coefficients (*125 Hz and 250 Hz*) of the suspended ceiling material must be higher in further treatments for optimal sound distribution in the hall.

5. SYMBOLS AND NOMENCLATURE

$L_{N,A}$	: A-weighted ambient noise level
L_{Aeq}	: Equivalent continuous A-weighted sound pressure level
Rw	: WeightedSound Reduction Index(for internal structural components)
Rw,res	: Sound Reduction Index(for exterior building components)
T_{30}	: Reverberation Time (s)
EDT	: Early Decay Time(s)
STI	: Speech Transmission Index
D50	: Definition
A	: Equivalent absorption area in the room
NS	: Average number of speaking persons
N	: Total number of people
g	: Average number of people per speaking person
V	: Total air volume
$T_{30,mid}$	: Reverberation Time (Calculated with 30 dB extinguishedness, 500 Hz and 1000 Hz in the average of the reverberation time)
$L_{S,A,1m}$	: The speech, at a distance of 1 meter, the A-weighted sound pressure level
SNR	: Signal-to-noise ratio
NCB	: Noise level curve

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