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Evaluation and Improvement of Reverberation Time in the Current Enclosed Spaces with Speech Action

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Abstract
There are subjective and objective acoustic parameters in the creation of acoustic performance for speech action in room acoustics. Control of reverberation time affecting subjective and objective acoustic parameters is a main parameter in room acoustics. In this study, the acoustic performance assessment of the TOBB Twins Headquarters Reception Hall, which is current enclosed space with square plan and flat floor, has been performed as a case study. The evaluation focused on the relationship between reverberation time and interior surface absorption. Primarily, the reverberation time was determined according to the international standard with in-situ measurements in the current enclosed space. The reverberation time of the space was found over the reference value range. Models have been developed with the use of materials to reduce the reverberation time. In the assessment of room acoustics parameters, reverberation times of the models developed using Ecotect v.5.20 and Odeon 14.00 simulation programs have been determined. The model in which the optimum reverberation time for the speech action was obtained was constructed. After the construction, reverberation time measurements have been made again. As a result of the study, the effect of surface absorptions on the improvement of reverberation time in the enclosed spaces with square plan and flat floor for speech action has been evaluated. Suggestions have been developed to control the reflective and absorption properties of all surfaces in accordance with the evaluation and improvement of reverberation time.
Keywords
room acoustics, acoustic performance, speech intelligibility, sound absorption, reverberation time

1 Introduction

Within the context of room acoustics in enclosed spaces for speech action, it is an important design criterion for speech to be intelligibility and effective. Speech intelligibility and its effective is provided by subjective and objective acoustic parameters in rooms (Ermann, 2015). Within this framework, room acoustic parameters should be created depending in the spaces used for the reception hall, meeting hall, conference hall and classrooms. The fact that the reverberation time, which has an important component in the parameters and affects other parameters, is designed with appropriate values affects the creation of other room acoustic parameters (early decay time, sound pressure level difference, speech transmission index, clarity, definition etc.) at appropriate values (Barron, 2010; Egan, 1988; Gramez and Boubenider, 2017).

Wallace Clement Sabine (1868-1919), in his acoustic performance evaluation; (Fogg Art Museum) determined that the reflected sound problems in the enclosed spaces were caused by the dimensions of the room, the interior equipment and the density of the people in the room. As a result of the studies, reverberation time was determined and the performance effects of reverberation time on the receiver were explained (Sabine, 1922). Thus, reverberation time has developed as the basis of room acoustic parameters studied for performance halls (Skålevik, 2010). Reverberation time was not sufficient to create room acoustic performance in the historical process; parameters such as receiver positions, early lateral reflections, homogeneous propagation of sound in room, and electro acoustic systems were also investigated and examined (Eldakdoky and Elkhateeb, 2017; Kurtay et al., 2008).

Reverberation time is related to the room geometry of the space and the total absorption of the room. Within the

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scope of total absorption, sound absorption coefficients, usage quantities of walls, ceiling and floor finishing materials and occupant characteristics are taken into consideration (Bradley, 1986). The required reverberation time is expected to be shorter in order for the speech action to be effective in reception halls than in halls contain music actions. Reverberation time (RT_{60}) is defined as the time taken to decrease the sound level (L_p) by 60 dB after the sound source is turned off within the enclosed spaces (Fig. 1). Reverberation time is calculated with the Eq. (1):

$$RT_{60} = 0.161 \times V/A , \quad (1)$$

where:

- RT_{60}: reverberation time (s),
- V: volume (m^3),
- A: total absorption (m^2 sabin),
- 0.161: empirical constant (s/m).

A relatively large number of studies have been conducted on the reverberation time in acoustic performance analyses in halls with speech action. Rudno-Rudziński and Dziechciński, investigated the effect of surface absorption to improve the reverberation time in Wrocław Opera House after restoration (Rudno-Rudziński and Dziechciński, 2006). Baştan et al. calculated the reverberation time of a conference room based on the room dimensions and acoustic properties of the indoor surface materials. Efficacy analyses on the reverberation time of acoustic materials were obtained by creating variations with different materials (Baştan et al., 2010). Mikulski and Radosz investigated the relationship between reverberation time and speech transmission index in different classrooms in primary school buildings. In their study, in order to improve the reverberation time in the classrooms, a recommendation was made to use carpets in ideal room volumes and floors' properties (Mikulski and Radosz, 2011). Daheng and Qi investigated the effectiveness of different reverberation time calculations (Sabine, Norris-Eyring and Millington-Sette) on the acoustic performance of the classroom (Daheng and Qi, 2012). Gómez Escobar and Barrigón Morillas investigated the relationship between background noise, speech transmission index and reverberation time in educational buildings through intelligibility (Gómez Escobar and Barrigón Morillas, 2015). Nowoświat and Olechowska created a rapid prediction model to determine the reverberation time and the speech transmission index. The success of the rapid prediction model reveals the importance of the reverberation time among other parameters (Nowoświat and Olechowska, 2016a). Nowoświat and Olechowska investigated reverberation time in terms of theoretical aspects and applicability potentials. They stated that different calculations and approaches are based on Sabine's statistical method (Nowoświat and Olechowska, 2016b). Eldakdoky and Elkhateeb obtained the optimum reverberation time in two different auditoriums by interfering with the ceiling shape and rear surfaces with sound absorption materials (Eldakdoky and Elkhateeb, 2017). Polewczyk and Jarosz conducted analyses for the reverberation time and the speech transmission index at various spaces (classrooms, sports hall, after-school clubs, corridors and halls) in a primary school and reported the evaluations of the analyses for compliance with national regulation, PN-B-02151-4:2015-06 (Polewczyk and Jarosz, 2020). Kurtay et al. investigated the effects of surface absorption on reverberation time in a conference hall and made analyses to provide optimum reverberation time (Kurtay et al., 2021). Zhou et al. conducted studies to estimate the reverberation time in rectangular rooms with inhomogeneous sound absorption distribution. The study discusses measuring and calculating distortion curves and reverberation time (Zhou et al., 2021). Wen et al. investigated the relationship between subjective evaluations and reverberation time to improve the acoustic properties of Beijing Opera Theatre. Young participants prefer a longer reverberation time, while experienced participants prefer a shorter reverberation time (Wen et al., 2022).

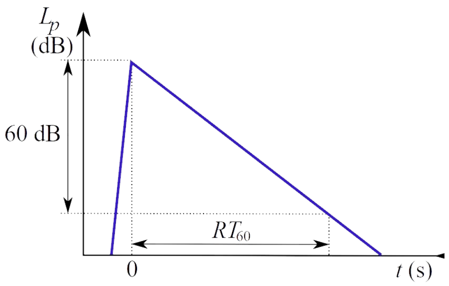


Fig. 1 Reverberation time (Piska, 2019)

Room acoustic parameters for the current enclosed spaces were evaluated in the TOBB Twins Headquarters Reception Hall as a case study. The study focused on evaluation and improvement reverberation time in the enclosed spaces with square plan and flat floor. In this study was limited to evaluate and improve the in-room reverberation time and investigating the effect of surface absorptions on reverberation time. Within the framework of the study, the following principles have been adopted in controlling the reverberation time:

- Different materials with high sound absorption coefficients were used considering the effect of reverberation time. The selection and use of materials that can be applied directly to the current enclosed spaces has been preferred as a priority.
- In the developed models, the purpose of use of the building has been evaluated and the receiver positioning has been used in such a way that it is valid for all models.
- Priority was given to 500 Hz and 1000 Hz (medium frequencies) frequencies where the human ear is sensitive.

2 Method of the study

TOBB Twins Headquarters Reception Hall was focused on the speech intelligibility as a case study and researches were conducted to examine reverberation time and surface absorptions. Primarily, in-room reverberation time was determined by taking in-situ measurements at 14 different points. Analyses aimed at improvement the current situation by Ecotect v.5.20 and Odeon 14.00 computer simulation programs have been conducted (Autodesk, 2007; Odeon, 2020).

Two different computer simulation programs used in the improvement of the reception hall are given in detail. Firstly, the Ecotect v.5.20 program, which was developed at Cardiff University, England, was first used in the geometric modeling and acoustic analysis of the hall (Autodesk, 2007). The program offers the option to perform a number of acoustic analyses. These analyses range from determining simple statistical reverberation times to complex point analyses and ray tracing techniques. With Ecotect v.5.20, it is possible to perform different analyses such as thermal performance analysis, shadow and shading, artificial and natural lighting levels, and cost analysis, in addition to acoustic analysis (Autodesk, 2007). Secondly, Odeon computer simulation program was used in the acoustic analysis of the hall. Ray tracing and image source algorithms are used in Odeon room acoustic simulations, which were first developed in 1987. It also transfers the scattering and diffraction of sound waves to the simulation through reflection-based scattering. The Odeon computer simulation program is run by modeling the surfaces of closed rooms in CAD programs in three dimensions and transferring the models to Odeon, with source-receiver positioning and material assignments to the interior surfaces. Odeon provides receiver-based calculation of acoustic parameters important in noise control and room acoustics, such as sound pressure level, reflection time, early decay time, speech transmission index. In addition, with its auralization properties, it provides auditory simulation of any point-based acoustic environment in the rooms (Naylor, 1993; Odeon, 2020).

The hall was calibrated and transferred to the computer simulation program within the framework of in-site measurements for the current situation analysis. Determining the duration of in-room reverberation time above the reference values made it necessary to propose different acoustic solutions from the current situation. Models for material uses and positions have been developed through computer simulation programs. The model (Model M8) in which the reference reverberation time was obtained and M8 was constructed in the reception hall. In-site measurements were made after construction. Spaces with square plan and flat floor have been evaluated according to reverberation time and surface absorptions.

3 TOBB Twins Headquarters Reception Hall current situation reverberation time and evaluation

There are four vertical structural elements in the TOBB Twins Headquarters Reception Hall, and there is an inverted dome-shaped suspended ceiling on the ceiling in the middle of the space. The total volume of the space is 2,722.992 m^3. Gypsum plaster was used as the finishing material in the wall and ceiling surfaces in the space. The floor was covered with laminate wood coating (Fig. 2). In the current situation of the room, the finishing materials cause the sound to be reflected at a high rate. Reflecting sound in rooms, increasing the reverberation time, in turn decreasing the intelligibility of direct/indirect speech.

Analysis of the reference reverberation time for the space to be examined was made 500 Hz and over (medium frequencies). The reference reverberation time for the speech action to be performed mostly in the current enclosed spaces is 0.9 s obtained within this case study, 0.85 s and 0,95 to be within the acceptable level of reverberation time (Fig. 3).

In the scope of the study, the current situation analyses of the TOBB Twins Headquarters Reception Hall were investigated. Measurements were made at 14 different points within the room. As part of the measurements, the sound source was adopted at the point where the temporary stage was located near the wall opposite the entrance door. As a result of the measurements, the reverberation time of the current situation is 1.72 s at 500 Hz and 1.58 s at 1000 Hz (Table 1). The current situation was calibrated to the computer simulation programs in accordance with the

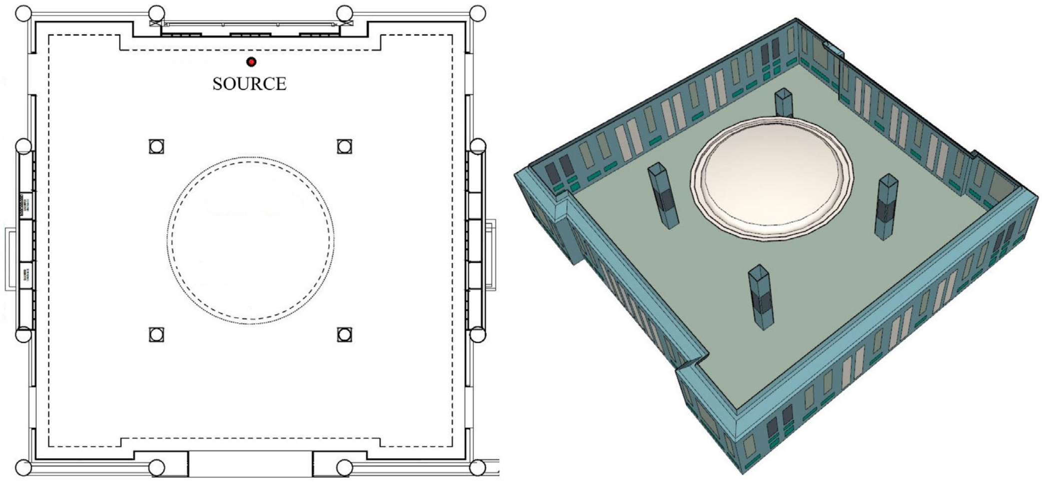


Fig. 2 Plan and 3D acoustics model of TOBB Twins Headquarters Reception Hall

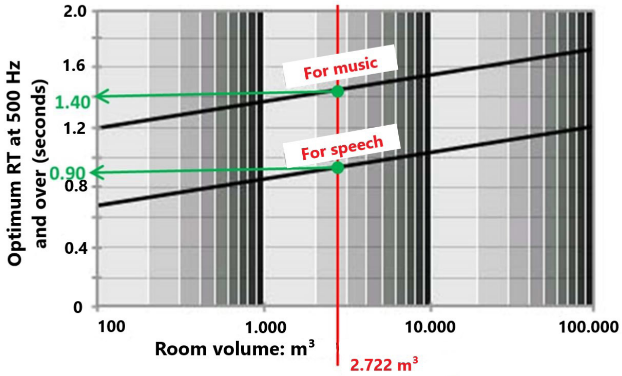


Fig. 3 Relations between the Reception Hall volume and the reference reverberation time of 500 Hz and over (Knudsen and Harris, 1988)

Table 1 Measurement results of the current situation reverberation time

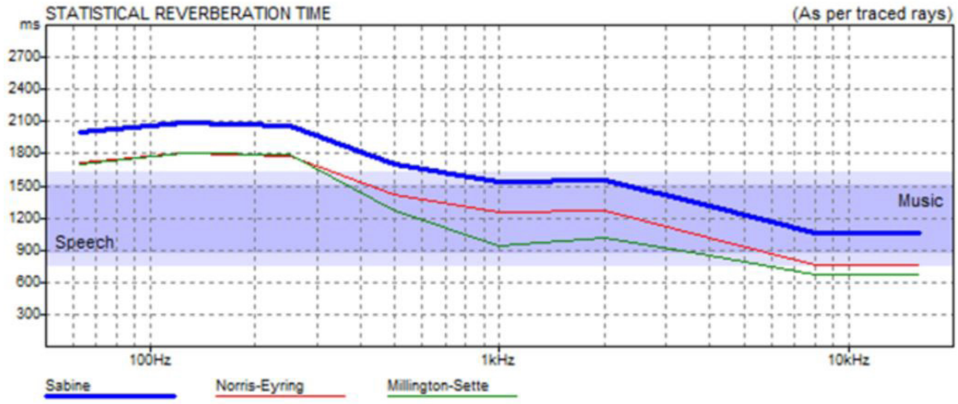
Reverberation time (s)	Frequency (Hz)						
	125	250	500	1000	2000	4000	8000
T_{20} (s)	2.10	1.92	1.71	1.59	1.55	1.32	0.94
T_{30} (s)	2.11	1.91	1.73	1.59	1.55	1.33	0.92
RT_{60} (s)	2.08	1.90	**1.72**	**1.58**	1.54	1.33	0.93

results obtained by in-site measurements and the reverberation time was transferred to 1.71 s at 500 Hz and 1.54 s at 1000 Hz (Fig. 4). 20.000 rays with 12 reflections were used in geometric acoustic analysis within the scope of simulations. In the current situation of the enclosed space, it was deemed necessary to make acoustic improvement recommendations to reduce the in-room reverberation time.

4 Models developed for acoustic improvement of TOBB Twins Headquarters Reception Hall

It has been deemed necessary to take measures to decrease the reverberation time in the current enclosed spaces. Accordingly, the sound absorption coefficients of the materials in the current enclosed space interior surfaces and the sound absorption coefficients of the materials to be used within the scope of the suggestions were examined and the materials given in Table 2 were determined to be transferred to the computer simulation programs.

Models have been developed with different position uses of the materials given in Table 2 in the space. Developed models are proposed to reduce and improve in-room reverberation time. Models were controlled through computer simulation programs and reverberation times were set at frequencies of 500 Hz to 1000 Hz within the models, it was determined that reverberation time appropriate to reference value ranges was obtained in Model M8 (Table 3,



FREQ.	TOTAL ABS.	SABINE-NOR-ER-MIL-SE RT(60)	RT(60)	RT(60)	
63Hz:	140.821	2.00	1.72	1.70	s
125Hz:	135.285	2.08	1.80	1.81	s
250Hz:	136.922	2.06	1.78	1.79	s
500Hz:	165.054	1.71	1.42	1.27	s
1kHz:	182.689	1.54	1.26	0.95	s
2kHz:	180.568	1.56	1.28	1.02	s
4kHz:	215.376	1.31	1.02	0.86	s
8kHz:	266.215	1.06	0.76	0.67	s

Fig. 4 Transfer of current situation reverberation time to computer simulation programs

Table 2 Sound absorption coefficients of materials used for acoustic improvement

Frequency (Hz)	63	125	250	500	1000	2000	4000	8000	a_w	Class
Gypsum Plaster (current)	0.26	0.26	0.26	0.27	0.29	0.30	0.39	0.52	0.30	D
Wood (Floor) (current)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	E
Fabric Covered Acoustic Panel[1]	0.03	0.01	0.3	0.72	1	1	0.97	0.95	0.60	C
Fabric Covered Acoustic Panel[2]	0.04	0.13	0.69	1	1	1	1	1	0.95	A
Carpet	0.08	0.08	0.23	0.57	0.7	0.7	0.75	0.75	0.50	D
Curtain	0.1	0.1	0.2	0.65	0.85	0.8	0.8	0.8	0.5	D
Gypsum Boards	0.3	0.4	0.55	0.8	0.8	0.7	0.64	0.64	0.75	C

[1] It covers acoustic panels with glass tulle and acoustic permeable fabric on the front side and glass tulle on the back side on a glass wool board with a thickness of 20 mm, density of 95 kg/m^3.
[2] It covers acoustic panels with glass tulle and acoustic permeable fabric on the front side and glass tulle on the back side on a glass wool board with a thickness of 40 mm, density of 95 kg/m^3.

Fig. 5). Model M8 (0.93 s at 500 Hz with 0.82 s at 1000 Hz) reverberation times obtained in frequency bands were found in the reference value ranges.

Within the framework of Model M8; use of fabric covered acoustic panels (40 mm) on walls upper levels, use of fabric covered acoustic panels (20 mm) on columns and doors upper levels, and use of curtains in glazed entrance doors was found appropriate. At the same time, it is considered necessary that the glazed entrance doors have curtains. (Figs. 6 and 7) Selection of materials with appropriate sound absorption coefficients is important for the validity of the computer simulation results in construction phase. It should be noted that the materials to be used have been tested within the framework of standards and sound absorption coefficients have been determined.

Model M8 developed within the scope of simulation results has been constructed to improve the current situation. As a result of the construction, in-room reverberation time was re-examined by making in-site measurements (Table 4).

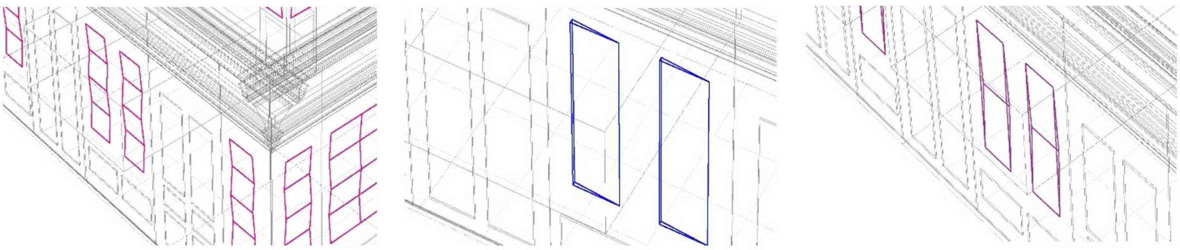
5 Results and discussion

TOBB Twins Headquarters Reception Hall examinations were conducted to improve the current reverberation time within the framework of room acoustic parameters for the speech action. Within the scope of the examination, reverberation time which is over the reference values in the space was tried to be reduced. Variations related to the absorption of in-room surface materials have been designed and models have been developed. Model M8,

Table 3 Developing models for improving reverberation time

Model code	TOBB Twins Headquarters Reception Hall (Analysis of Use and Position of Materials)	Reverberation time, RT_{60} (s)	
		500 Hz	1000 Hz
M1	Current Situation (in-site measurements) (Gypsum plaster of walls and ceiling, wood laminate coating on floor)	1.72	1.58
M2	Use of fabric covered acoustic panels (20 mm) on walls and columns upper levels	1.22	0.96
M3	Use of fabric covered acoustic panels (20 mm) on walls and columns upper and lower levels	1.22	0.96
M4	Use of fabric covered acoustic panels (20 mm) on walls and columns upper and lower levels & use of carpet in the middle of floor	1.22	0.96
M5	Use of fabric covered acoustic panels (20 mm) on walls, columns and doors upper levels & use of curtains in glazed entrance doors	1.09	0.83
M6	Use of fabric covered acoustic panels (20 mm) on walls, columns and doors upper levels, use of curtains in glazed entrance doors & use of fabric covered acoustic panels (20 mm) exclude of inverted dome on the ceiling	1.07	0.82
M7	Use of fabric covered acoustic panels (20 mm) on walls and columns upper levels, use of curtains in glazed entrance doors & use of acoustic gypsum boards on gypsum plaster walls	0.87	0.70
M8	Use of fabric covered acoustic panels (40 mm) on walls upper levels, use of fabric covered acoustic panels (20 mm) on columns and doors upper levels & use of curtains in glazed entrance doors	**0.93**	**0.82**
M9*	Use of fabric covered acoustic panels with angled four-piece layout from upper to lower (20 mm) on walls and columns upper levels, use of fabric covered acoustic panels (20 mm) on doors upper levels, use of curtains in glazed entrance doors	0.62	0.53
M10*	Use of fabric covered acoustic panels with angled in plan single-piece (20 mm) on the two side walls, use of fabric covered acoustic panels (20 mm) on columns and doors upper levels & use of curtains in glazed entrance doors	1.05	0.80
M11*	Use of fabric covered acoustic panels with angled two-piece layout from upper to lower (20 mm) on walls and columns upper levels, use of fabric covered acoustic panels (20 mm) on doors upper levels & use of curtains in glazed entrance doors	0.70	0.60
M12*	Use of fabric covered acoustic panels with angled two-piece layout from upper to lower (20 mm) on the two side walls, use of fabric covered acoustic panels (20 mm) on other walls, columns and doors upper levels & use of curtains in glazed entrance doors	0.90	0.73

* Details for Model M9, M10, M11 and M12 are given in Fig. 5.



(a) (b) (c)

Fig. 5 Angled panel positions used in models; (a) M9; (b) M10; (c) M11-M12

which has values of 0.93 s at 500 Hz to 0.82 s at 1000 Hz, was applied as the reverberation time in room and reverberation time was determined by taking in-site measurements again (Fig. 8).

The reaching reference value for the reverberation time after the construction in the reception hall was around 83%. The main factor that reduces the success ratio in the scope of the study is that it is predicted that glazed entrance doors will be enclosed with curtains in computer simulation programs for Model M8, but this situ has not implemented in constructions and acoustic measurements. According to the results of the simulation, it is stated that if the curtain (aw 0.5), which has a high sound absorption coefficient, is used in glass inputs, it will provide a high level of absorption in the enclosed space and will be effective in reducing reverberation time. The current reverberation time must be reduced by 0.82 s to achieve the reference reverberation time. The value in the reverberation time required to be reduced is rated as a percentage of reaching the reference value at 500 Hz. The evaluations

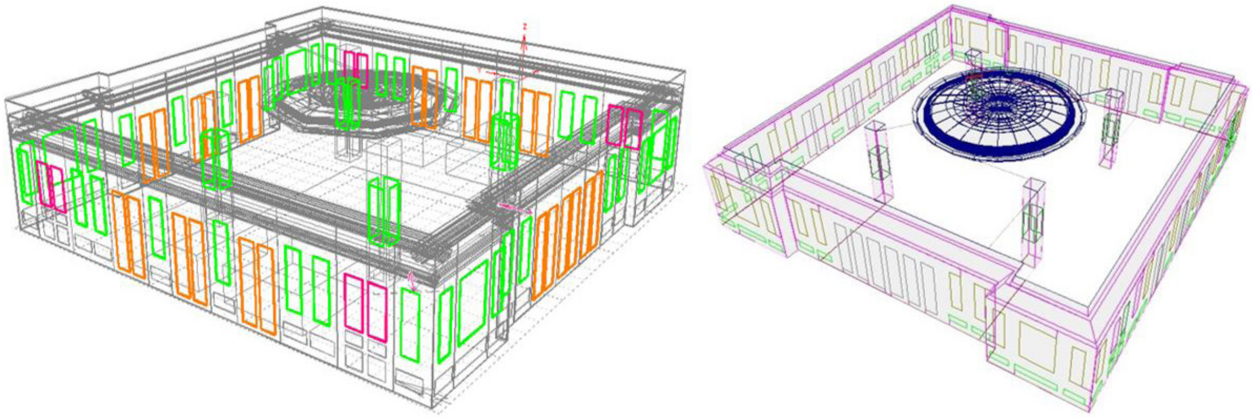
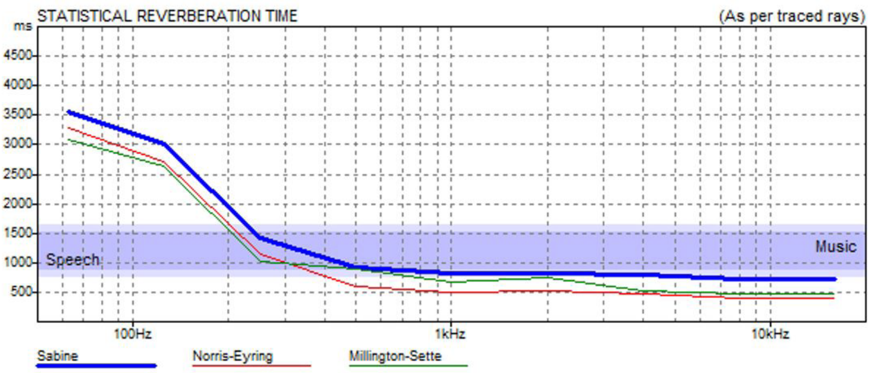


Fig. 6 Layout of materials used for Model M8 from Ecotect v.5.20 and Odeon 14.00 computer simulation programs (Autodesk, 2007; Odeon, 2020)



FREQ.	TOTAL ABS.	SABINE RT(60)	NOR-ER RT(60)	MIL-SE RT(60)	
63Hz:	85.294	3.55	3.27	3.09	s
125Hz:	100.846	3.00	2.72	2.65	s
250Hz:	211.390	1.43	1.14	1.02	s
500Hz:	327.070	0.93	0.62	0.91	s
1kHz:	367.835	0.82	0.51	0.68	s
2kHz:	360.921	0.84	0.52	0.75	s
4kHz:	378.575	0.80	0.48	0.53	s
8kHz:	412.169	0.73	0.41	0.48	s
16kHz:	412.169	0.73	0.41	0.48	s

Fig. 7 Reverberation time of Model M8 simulation

Table 4 Measurement results of reverberation time after construction

Reverberation time (s)	Frequency (Hz)						
	125	250	500	1000	2000	4000	8000
T_{20} (s)	1.85	1.38	1.03	1.04	1.06	1.04	0.87
T_{30} (s)	1.76	1.46	1.04	1.03	1.08	1.04	0.84
RT_{60} (s)	1.85	1.38	**1.04**	**1.03**	1.08	1.04	0.84

and graphic representation made within the scope of the study are given below (Fig. 9):

- The use of Class C sound absorption material on the walls and columns, and carpet in the middle part of the floor decreased the reverberation time by 0.5 s. Achieving reference value was around 60%.
- The use of Class C sound absorption material on the walls and columns; the glazed entrance doors with curtains reduced the reverberation time by 0.63 seconds. Achieving reference value was around 76%. When the Model M3 and M5 are compared, the glazed entrance doors with curtain brought the reverberation time closer to the reference value range.
- The use of Class C sound absorption material on the walls and columns, the glazed entrance doors with curtains, and the use of sound absorption

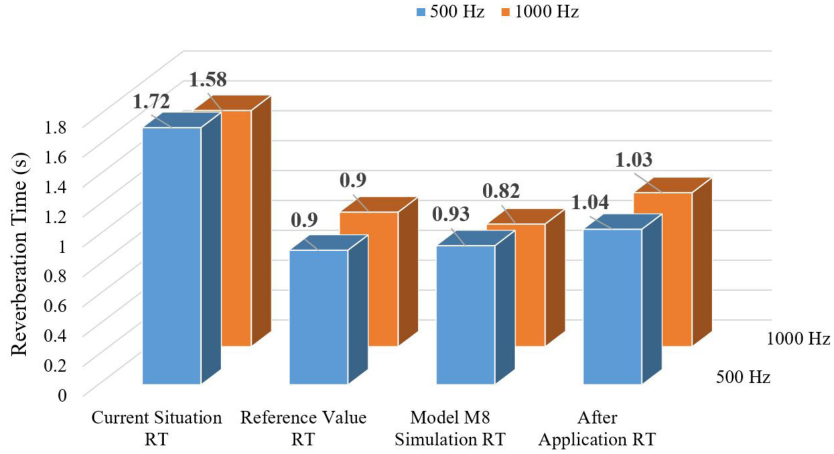


Fig. 8 Improvement phases of reverberation time in current enclosed space

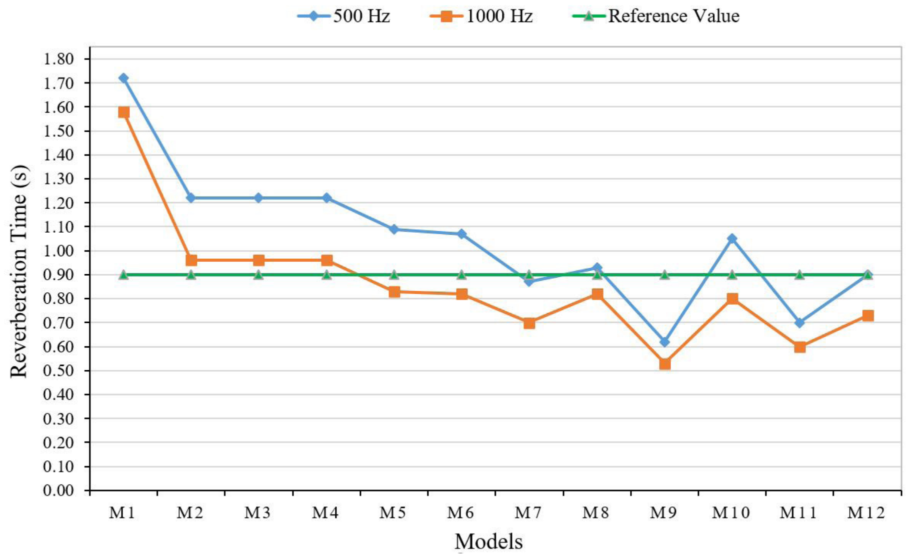


Fig. 9 Comparison of the reverberation times of the developed models

materials other than the inverted dome on the ceiling decreased the reverberation time by 0.65 seconds. Achieving reference value was around 79%. However, the model was not found suitable when efficacy analysis assessment was made with the intervention on the ceiling.

- The use of Class C sound absorption material on the walls and columns, the glazed entrance doors with curtains, and the use of sound absorption material on the rest of the wall decreased the reverberation time more than the reference value. In addition, the model was not found suitable when the efficacy analysis assessment was made with the intervention on the wall.
- The use of Class A sound absorption material on the walls and use of Class C sound absorption material on the door and column upper levels reduced reverberation time by 0.79 s. Achievement of reference value was around 96%.
- The use of angled positions of the sound absorption materials on the walls reduced the reverberation time more than the reference values at different frequencies. Increasing the number of angled positions used and usage areas in the room has been effective in reducing the reverberation time.

6 Conclusion

The control of the reverberation time is an important design criterion for the speech to be intelligibility and effective in the examination of room acoustics in halls with speech action. In order to provide the reference reverberation time in current enclosed spaces, the sound absorption coefficients and usage quantities of the interior surface finishing materials to be used in the space are important. Within the scope of the study, the example of a hall with square plan and flat floor has been evaluated, examined and improvements have been made.

The relationship between surface absorption and reverberation time varies according to material positions, usage quantities and sound absorption coefficients of materials. As a result of the examination, when the reverberation time and the surface absorption in the spaces with square plan and flat floor were taken into consideration, the effect of the vertical building elements (walls, columns, windows and doors) on the reverberation time was higher than the horizontal elements (ceiling and floor). Closing the elements with high reflectivity properties in the enclosed spaces with the absorption properties of materials provided the in-room reverberation time to remain at reference value ranges. Within the scope of the study, it is recommended to use the materials with high sound absorption coefficients in vertical building elements and then use them in horizontal elements in order to decrease the reverberation time in the current enclosed spaces with square plan and flat floor for speech action. Angled position of the materials used in the developed models has been effective in reducing the reverberation time. It is recommended that the use of this type of material is distributed uniformly and homogenous throughout the enclosed space. Within the scope of the examinations, the surface absorption of the current situation should be examined and assessment should be made with the reverberation time.

References

Autodesk "Ecotect, (Version v5.20)" [computer program] Available at: http://www.squ1.com [Accessed: 01 May 2007]

Baştan, N. C., Baştan, Ö. A., Erdem Aknesil, A. (2010) "Salonlarda akustik konfor koşullarının belirlenmesi ve değerlendirilmesine yönelik bir etüt çalışması" (A case study to determine and evaluate acoustic comfort conditions in halls), In: 1. International Graduate Research Symposium on the Built Environment, Ankara, Turkey, pp. 73–78. ISBN 978-975-429-286-2 (in Turkish)

Barron, M. (2010) "Auditorium Acoustics and Architectural Design", Spon Press. ISBN 9780419245100

Bradley, J. S. (1986) "Predictors of speech intelligibility in rooms", The Journal of the Acoustical Society of America, 80(3), pp. 837–845. https://doi.org/10.1121/1.393907

Daheng, Y., Qi, L. (2012) "Research of Computer Simulation of Reverberation Time in Classroom", Physics Procedia, 33, pp. 1677–1682. https://doi.org/10.1016/j.phpro.2012.05.270

Egan, M. D. (1988) "Architectural Acoustics", McGraw-Hill College. ISBN 9780070191112

Eldakdoky, S., Elkhateeb, A. (2017) "Acoustic improvement on two lecture auditoria: Simulations and experiment", Frontiers of Architectural Research, 6(1), pp. 1–16. https://doi.org/10.1016/j.foar.2016.11.002

Ermann, M. (2015) "Architectural Acoustics Illustrated", John Wiley & Sons, Inc. ISBN 978-1-118-56849-1

Gómez Escobar, V., Barrigón Morillas, J. M. (2015) "Analysis of intelligibility and reverberation time recommendations in educational rooms", Applied Acoustics, 96, pp. 1–10. https://doi.org/10.1016/j.apacoust.2015.03.001

Gramez, A., Boubenider, F. (2017) "Acoustic comfort evaluation for a conference room: A case study", Applied Acoustics, 118, pp. 39–49. https://doi.org/10.1016/j.apacoust.2016.11.014

Knudsen, V. O., Harris, C. M. (1988) "Acoustical designing in architecture", Acoustical Society of America. ISBN 9780883182673

Kurtay, C., Irklı Eryıldız, D., Ulukavak Harputlugil, G. (2008) "Mimar Kemaleddin Salonu Akustik Performans Değerlendirmesi ve Performans İyileştirme Önerileri" (Acoustical performance evaluation of Mimar Kemaleddin Hall and alternatives for performance improvement), Journal of Faculty of Engineering and Architecture of Gazi University, 23(3), pp. 557–568. [online] Available at: https://dergipark.org.tr/pub/gazimmfd/issue/6677/88516 [Accessed: 28 September 2020] (in Turkish)

Kurtay, C., Ulukavak Harputlugil, G., Yaman, M. (2021) "Kare planlı yüksek tavanlı hacimlerde ses yutucu malzemelerin konumlarına göre reverberasyon süresine etkisi" (Effects of sound absorption materials on reverberation time according to their positions inthe square plan and high ceiling rooms), Journal of Faculty of Engineering and Architecture of Gazi University, 36(4), pp. 2069–2079. [in Turkish] https://doi.org/10.17341/gazimmfd.698997

Mikulski, W., Radosz, J. (2011) "Acoustics of Classrooms in Primary Schools – Results of the Reverberation Time and the Speech Transmission Index Assessments in Selected Buildings", Archives of Acoustics, 36(4), pp. 777–793. https://doi.org/10.2478/v10168-011-0052-6

Naylor, G. M. (1993) "ODEON—Another hybrid room acoustical model", Applied Acoustics, 38(2–4), pp. 131–143. https://doi.org/10.1016/0003-682X(93)90047-A

Nowoświat, A., Olechowska, M. (2016a) "Fast estimation of speech transmission index using the reverberation time", Applied Acoustics, 102, pp. 55–61. https://doi.org/10.1016/j.apacoust.2015.09.001

Nowoświat, A., Olechowska, M. (2016b) "Investigation Studies on the Application of Reverberation Time", Archives of Acoustics, 41(1), pp. 15–26. https://doi.org/10.1515/aoa-2016-0002

Odeon "Odeon room acoustics software, (Version 14.00)", [computer program] Available at: https://odeon.dk/ [Accessed: 28 September 2020]

Polewczyk, I., Jarosz, M. (2020) "Teachers' and Students' Assessment of the Influence of School Rooms Acoustic Treatment on Their Performance and Wellbeing", Archives of Acoustics, 45(3), pp. 401–417.
https://doi.org/10.24425/aoa.2020.134057

Piska, D. (2019) "Acoustics Theory – Sound Behaviour in Closed Space", RDacoustic, March 30. [online] Available at: https://www.rdacoustic.cz/en/blog/2019/03/30/acoustics-theory-sound-behaviour-in-closed-space/ [Accessed: 28 September 2020]

Rudno-Rudziński, K., Dziechciński, P. (2006) "Reverberation time of Wrocław Opera House after restoration", Archives of Acoustics, 31(4) (Supplement), pp. 247–252.

Sabine, W. C. (1922) "Collected papers on acoustics", Harvard University Press, London, UK.

Skålevik, M. (2010) "Reverberation time-the mother of all room acoustical parameters", presented at Baltic-Nordic Acoustics Meeting 2010 (BNAM 2010), Bergen, Norway, May 10–12.

Wen, M., Ma, H., Yang, J., Yang, L. (2022) "Main acoustic attributes and optimal values of acoustic parameters in Peking opera theaters", Building and Environment, 217, 109041.
https://doi.org/10.1016/j.buildenv.2022.109041

Zhou, X., Späh, M., Hengst, K., Zhang, T. (2021) "Predicting the reverberation time in rectangular rooms with non-uniform absorption distribution", Applied Acoustics, 171, 107539.
https://doi.org/10.1016/j.apacoust.2020.107539