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Acoustical Design and Experimental Validation of an NVH Listening Room

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ABSTRACT

NVH Laboratory of TOFAS, Turkish joint venture of FIAT Inc., necessitated a professional listening environment to evaluate noise data obtained from several performance tests on their vehicles. Despite limitations on listening room volume and boundaries, geometry of the environment is kept quite simple while the acoustical comfort parameters defined for a listening experience are preserved. The preliminary design stage focused on two main objectives, namely, isolation of the environment from its surrounding to lower interior background noise levels to minimum and sustaining high level acoustical comfort for listening experiences. Rectangular form is chosen for the environment for the sake of simplicity in design and construction. In dimensioning the environment within limited available space, room modes are taken into account for low frequency response. The computer simulation for the design is performed on room acoustic software, ODEON v12. Predictions obtained from the software for mid-to-high frequency behavior are comparatively evaluated with acoustical measurements. The outcomes from both software and measurements conducted with respect to ISO 3382 are found to be in agreement and consistent indicating that the objectives set at the design stage is fully accomplished.

Keywords: Room Acoustics, Listening Environment Design

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1. INTRODUCTION

NVH Department of TOFAS, Turkish Joint Venture of FIAT Inc., necessitated a professional listening environment to analyze noise and sound data obtained from several vehicle performance tests. This study focuses on the design stage of the environment from room acoustics point of view. Since the available resources considering the allocated volume for the project was limited, necessary improvements are taken into account during the design and construction stages. Furthermore, experimental validation of the environment, regarding several room acoustics parameters as well as the background noise levels, is performed after the construction of the environment is complete.

2. ACOUSTICAL DESIGN OF THE ROOM

The design of the listening environment includes several subjects regarding building and rooms acoustics. To keep background noise levels at minimum, airborne and structure borne sound transmission to the room should be kept at minimum. On the other hand, functionality of the environment should be justified for listening experiences; that is, room acoustics parameters within the room should fall in certain limits.

It is obvious that the very first parameter that should be determined and set is the background noise levels within the listening room. Since the environment is built for listening experiences, the noise criterion within the room is set as the criterion defined for recording and broadcasting studios. Recommended noise criterion for HVAC system within the recording studios is defined NC 15-25 [1].

The listening room is located in NVH laboratory where high noise intrusion into the room is inevitable. Consequently, necessary sound insulation is provided to keep external noise intrusion at minimum levels. Box in box model is used for room construction where the walls and ceiling of the room provide a sound transmission class value of Rw 60. Similarly, room floor provides a sound transmission class value of Rw 75. Sound transmission class values of the walls, ceiling and floor are determined with respect to the measured noise levels within the NVH laboratory when all test equipment are running. Since it is not the main focus of this study, sound insulation calculations and design are not given in detail in this text.

The listening room is constructed over a suspended floor in the NVH laboratory. Since the available volume is small, a rectangular shaped form is chosen for the geometry to constitute all of the available volume as the inner space of the room. Knowing that rectangular shape is a poor construction for architectural acoustic purposes, several treatments are done to improve low frequency response of the environment. Inner dimensions of the available volume are 6.00x5.87x3.29m (length x width x height). To minimize cross modes at low resonance frequencies room dimensions are rearranged [2]. Final dimensions of the room within applicable room ratio limits are 4.90x5.87.2.80m (length x width x height) while room volume is kept maximized. Furthermore, avoid parallel wall reflections room ceiling is tilted to give a gradient to the ceiling.

Since low frequency response is very cruel in small rooms, loudspeakers are positioned not to excite low frequency modes. The first mode along width occurs at 70Hz. Loudspeakers are positioned 61cm away from side walls which corresponds to dip position of the 4^{th} mode along width. Along room height, loudspeakers are positioned 1.74cm away from room floor, which corresponds to the dip position of the 4^{th} mode along the height. Unfortunately; in order not to lose space from room volume, loudspeakers are positioned close to the front wall of the listening room. Therefore some colorization may occur on fundamental frequency and its harmonics of the room modes along length. The fundamental mode along room length occurs at 58Hz. Consequently; at 58Hz and its harmonics there might be amplification due to reinforcement within the room. Similarly, listener locations are determined away from the spots where peaks of room modes occur in the room. However, the arrangement of listener positions is not set as did conscientiously in loudspeaker positions.

The reverberation time is still an important design parameter. For average listening room (or control rooms for recording studios) volume, which is almost 80 m3 in this case, the reverberation times varies from 0.3 to 0.4s [2].

Room geometry defined in the software is given in Figure 1. For cosmetic purposes room walls and ceiling are kept as gypsum board panels while room floor is covered with carpet. To maintain global estimate of reverberation time at certain levels, room walls and the ceiling are treated. Firstly, ceiling area is divided into two regions. Outer region of the ceiling (closer to the ceiling edges) is covered with ordinary gypsum board panels. The inner region is covered with perforated gypsum board panels having mineral wool layer behind. Similarly; to increase amount of absorbing surfaces within the room, porous absorbers are utilized on room walls. Porous absorbers are distributed over each wall with a different pattern to create uneven absorbing and reflecting surfaces. Detailed information about material list is given in Table 1.

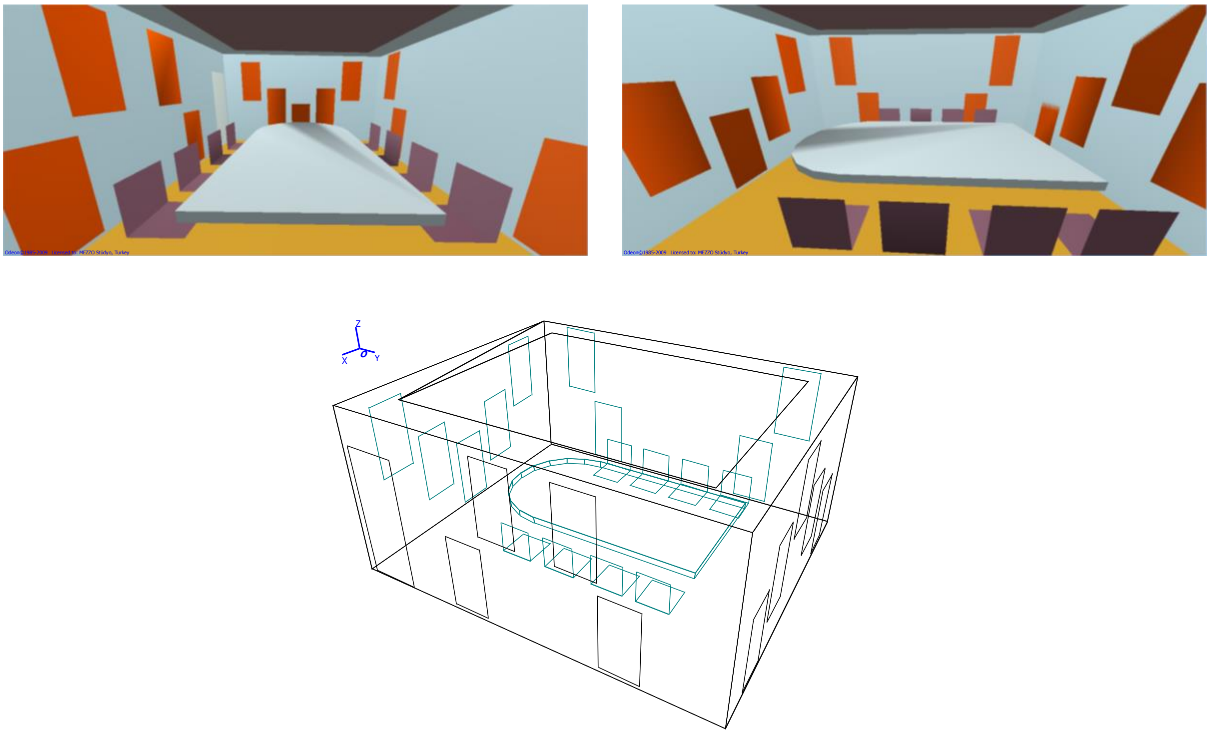

Figure 1 – Room Geometry

Table 1 – Sound absorption coefficients of surface materials

Surface Material	Sound Absorption Coefficient							
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Wooden Furniture	0,140	0,140	0,100	0,070	0,050	0,050	0,050	0,050
Medium upholstered seats	0,400	0,400	0,500	0,580	0,610	0,580	0,500	0,500
Walls (Gypsum Boards)	0,280	0,280	0,120	0,100	0,170	0,130	0,090	0,090
Wooden Doors	0,140	0,140	0,100	0,060	0,080	0,100	0,100	0,100
Floor (Carpet)	0,010	0,010	0,050	0,160	0,260	0,680	0,760	0,680
Absorber Panels	0,110	0,110	0,320	0,560	0,770	0,890	0,910	0,910
Suspended Ceiling (Ordinary Gypsum Board)	0,180	0,180	0,140	0,110	0,060	0,070	0,090	0,090
Suspended Ceiling (Perforated Gypsum Boards)	0,350	0,350	0,450	0,500	0,500	0,450	0,500	0,500

3. PREDICTION RESULTS

Room acoustic simulations performed in ODEON v12.00 are used to predict room parameters. Global estimate of reverberation time as well as reverberation time (T30), A-weighted sound level (SPLA) and speech transmission index (STI) distribution maps are obtained from simulations and demonstrated through Figure 2 to Figure 5.

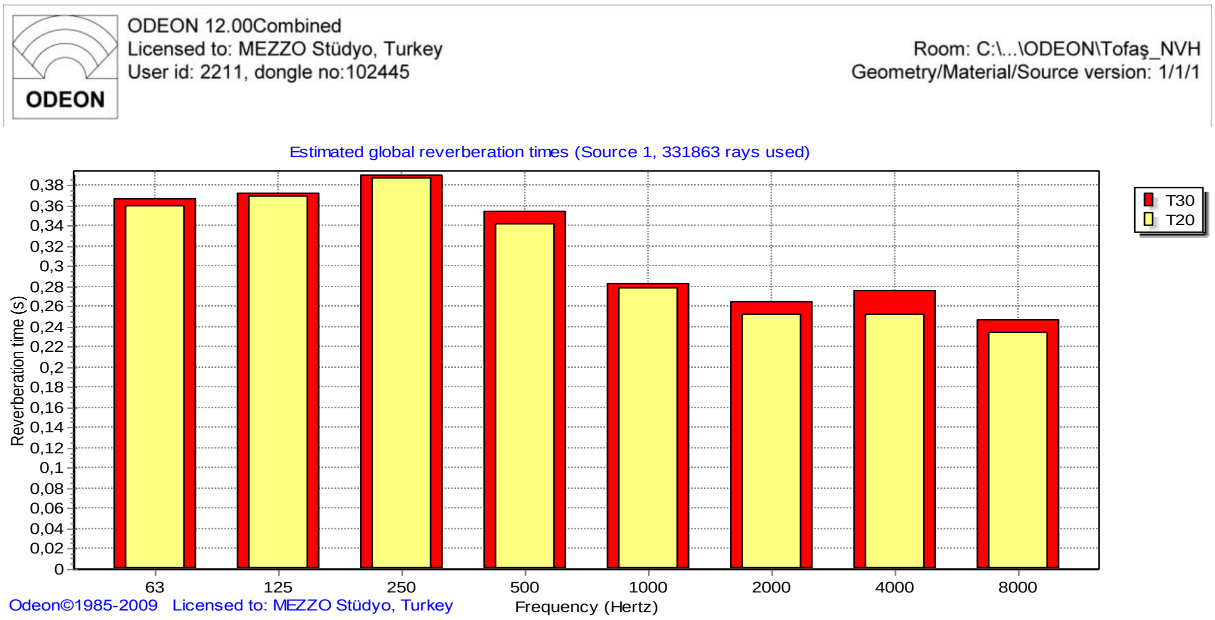

Figure 2 – Global estimates of reverberation time

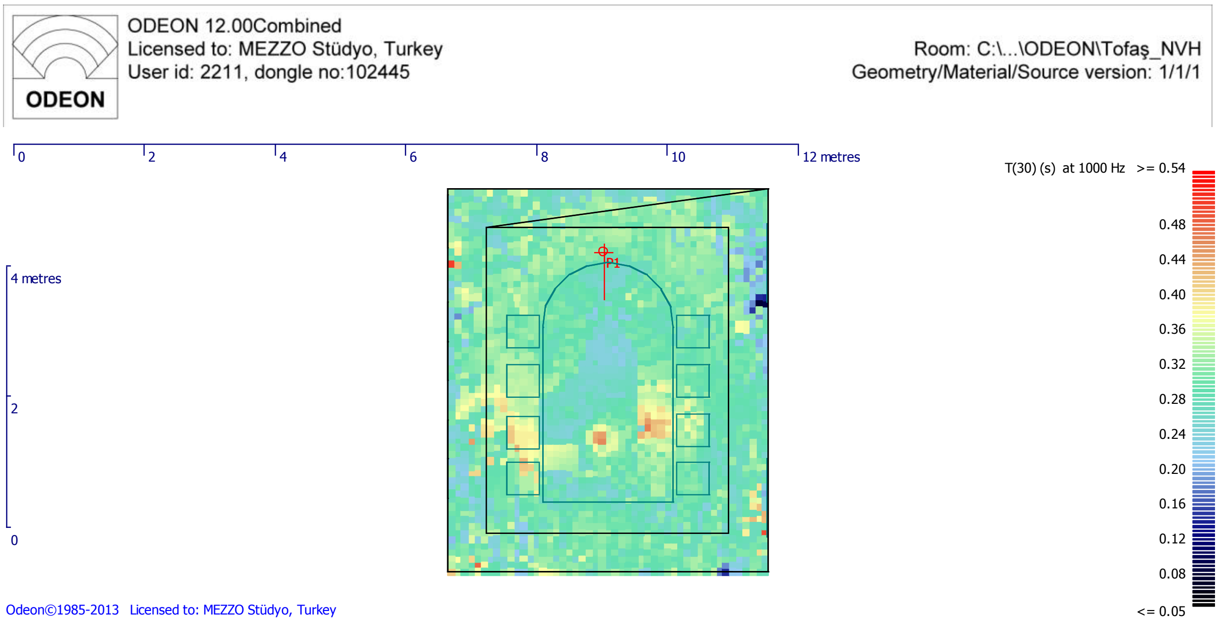

Figure 3 – Reverberation time (T30) distribution map (1000 Hz)

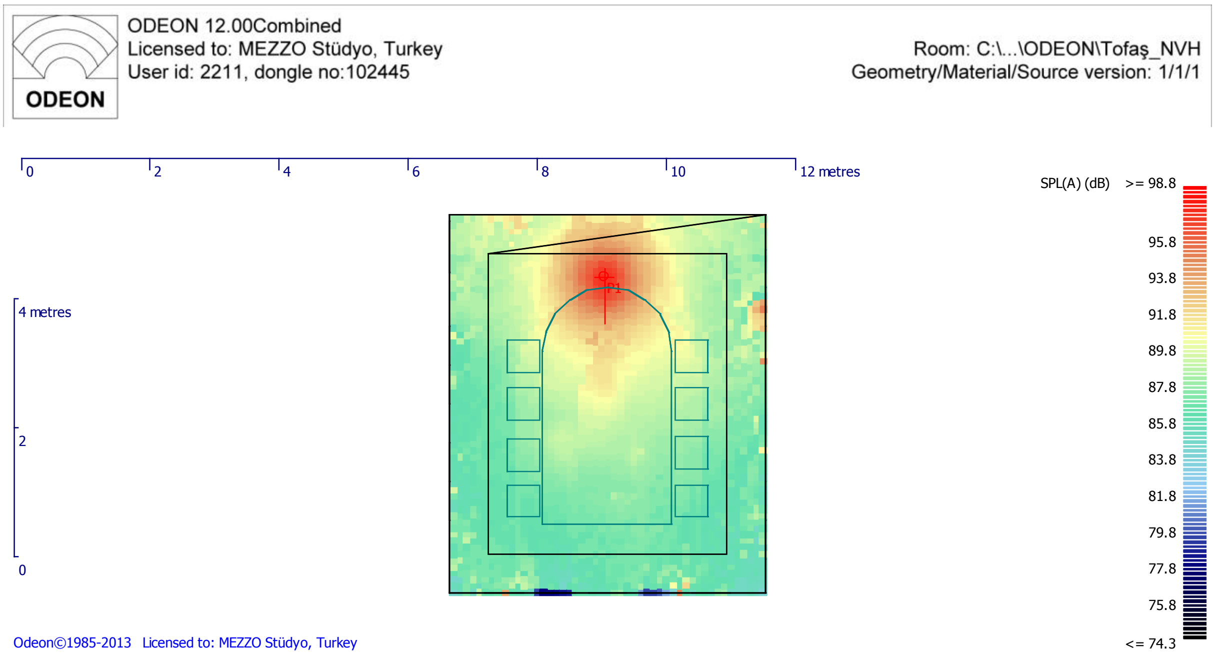

Figure 4 – SPL(A) Distribution map

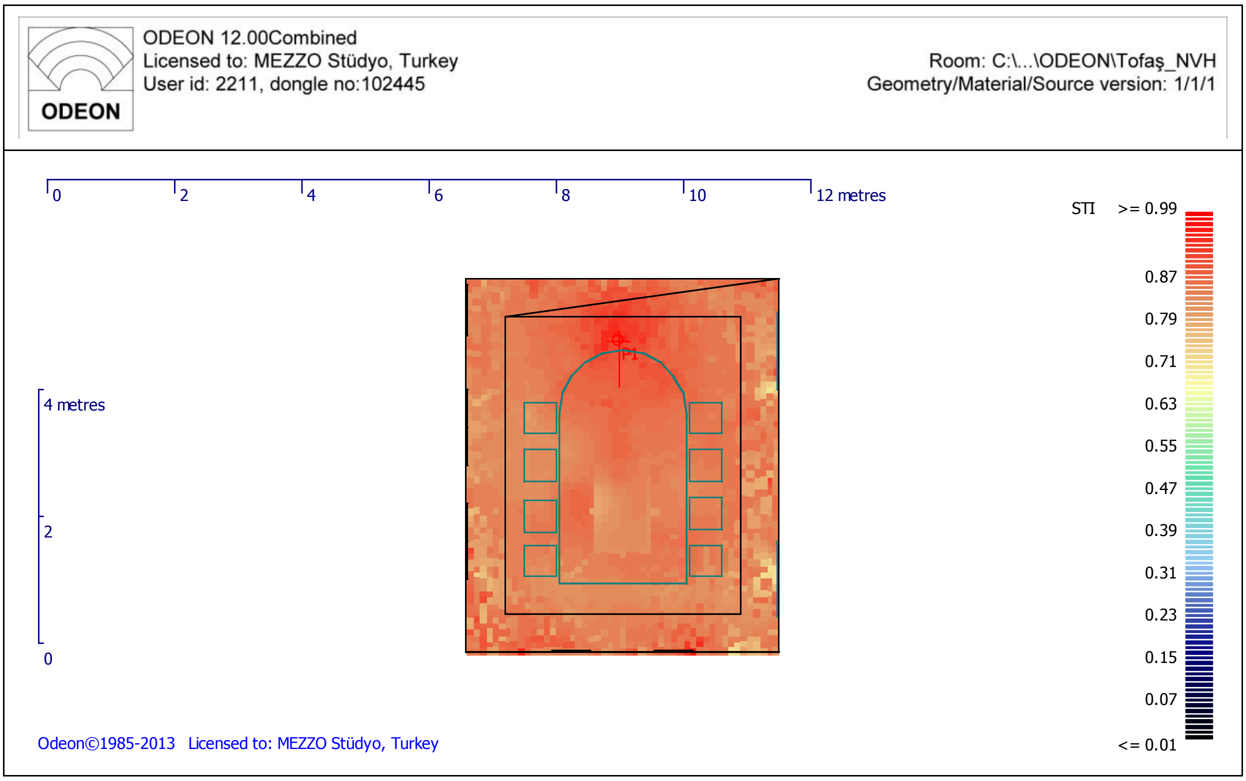

Figure 5 – STI Distribution map

4. MEASUREMENTS AND RESULTS

For the final stage, after all minor details are completed, room acoustic measurements conducted to verify room parameters predicted in the design stage. Bruel & Kjaer DIRAC Room Acoustics v4.1 software is used to generate sound field within the room as well as to obtain and interpret impulse responses at different receiver locations. 10 receiver positions are distributed over the room area to collect data generated from 1 source location (Figure 6). During the measurements ambient temperature is recorded as 22.3 ^{o}C and relative humidity is recorded as %26. Background noise levels when HVAC unit is operating are obtained and demonstrated in Figure 7. The duration of the measurement is set to 2 min and $L_{eq,2m}$ results are obtained in 1/3 octave bands. Background noise levels and average reverberation time (T20, T30) results are given in Table 2 and Table 3.

Figure 6 – Source location during the measurements within the listening room

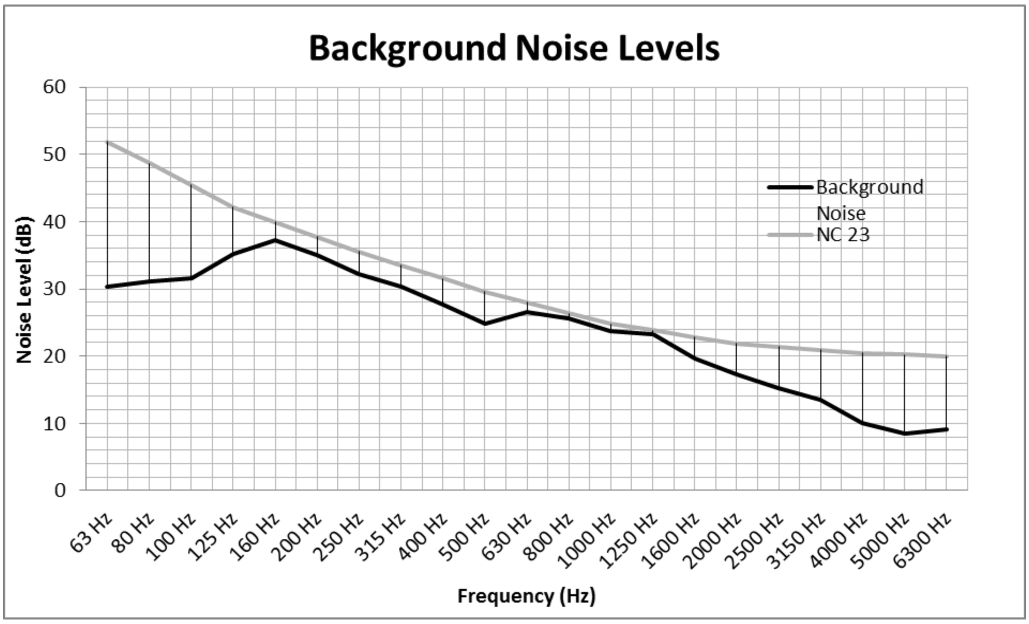

Figure 7 – Background noise levels with operating HVAC unit

Table 2 – Background noise levels with operating HVAC unit

Background Noise Levels [dB]									
63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz
30.3	31.1	31.6	35.2	37.3	35.1	32.2	30.3	27.7	24.9
630 Hz	800 Hz	1000 Hz	1250 Hz	1600 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	5000 Hz
26.5	25.6	23.7	23.3	19.7	17.3	15.3	13.5	10.0	8.5

Table 3 – Average reverberation time (T20, T30)

	Average Reverberation Time [s]							
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
T 20	0.46	0.45	0.40	0.28	0.25	0.22	0.21	0.21
T 30	0.48	0.47	0.43	0.29	0.26	0.21	0.22	0.21

5. CONCLUSIONS

In this paper, design stage and verifying in-situ measurements of a listening room in NVH department of TOFAS are presented. Apparently, it is a very common application of room acoustics for listening environments although some technical limitations are come across in the design stage. The location of the listening room and its limited volume is the major limitation that leads the design phase to construct simpler room geometry. Despite rectangular shaped room geometry, sufficient treatments are constituted in the design stage to eliminate excess amount of sound energy built up and uneven sound distribution within the room.

When the predetermined noise criterion and simulation results are compared with the measurement results, consistent outcomes are observed. Noise criterion defined for the listening room is NC 15-25. Measurements show that background noise levels fall below NC 23 curve, which is in the range of defined noise criterion.

Average reverberation time results obtained from the measurements and predicted global estimates of reverberation time are given in Figure 8. Results are consistent in almost every octave band except 63Hz and 125Hz. The reason for that can be explained by Schroeder frequency of the room. For measured reverberation times the Schroeder frequency is calculated as 127.1Hz [3] which gives a clear insight about the inconsistent behavior of reverberation times at low frequencies due to the fact that ray tracing approach in ODEON software fails to predict low frequency response of the room.

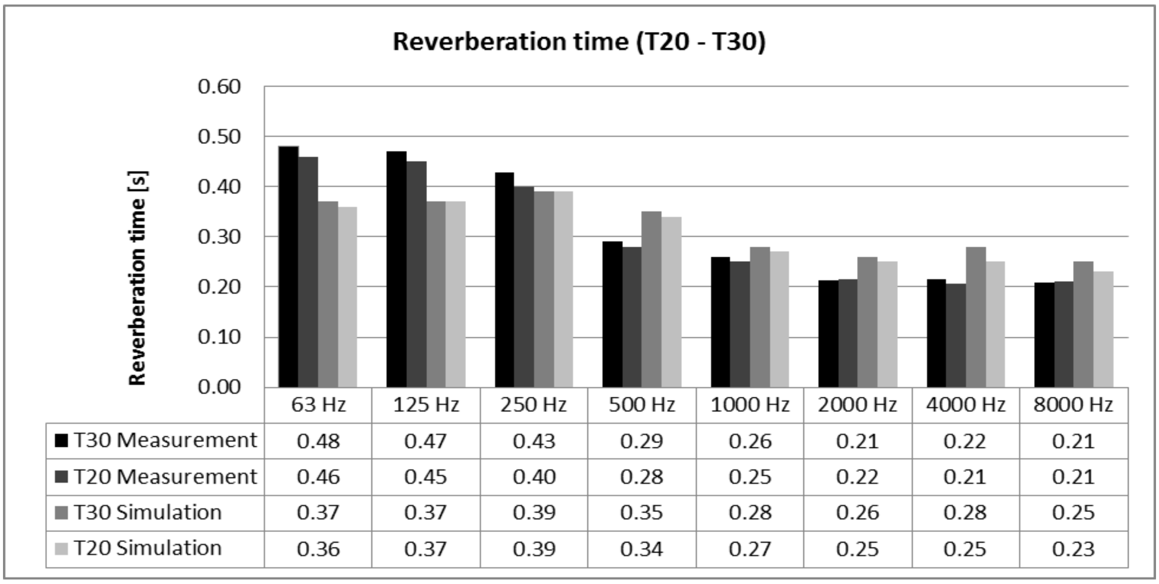

Figure 8 – Measurement and simulation results of reverberation time

When looked at the STI distribution map from simulation results, measurement results fall in the range of min and max values (0.85 – 0.91) observed in the distribution map. Even if the room is designed for listening experiences, it is also sufficient for speech activities that might take place within the room. Furthermore, difference between max and min values of sound level distribution within the room is 2.5dB at most showing that almost even sound distribution is achieved.

ACKNOWLEDGEMENTS

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