The Acoustic Analysis of a Single Room

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Abstract – **This paper describes the acoustic analysis of the parameters for a single room intended for meetings. In the first part of this paper both objective and subjective acoustic parameters are described in accordance with ISO 3382 standard. In the second part of the paper an experiment was done in which the acoustic impulse responses were practically measured. Then the graphical and tabular presentation of both subjective and objective parameters results set out of the acoustic impulse response was shown. Finally, the comparative analysis of acoustic parameters values along with the recommended values of ISO 3382 standard was done, and based on that, the acoustic quality of the room was evaluated in terms of its application.**

Keywords – **Room Impulse Response (RIR), Acoustic parameters, Reverberation.**

I. Introduction

The beginning of any acoustic measurements is attributed to Sabine, who was first to measure the reverberation time in 1900 [1]. Since then, we have reached significant discoveries which allow to obtain good acoustic of a certain space, whether it was speech intelligibility or music quality.

The analysis *Acoustic Impulse Response* (AIR) of rooms is an important part in mere acoustic interpretation of rooms. Room impulse response contains all the information about the acoustic characteristics of a room between the source position and the receiver position. During the transmission of a sound from a source to a certain receiving point within a room, the main characteristic of the room as an acoustic transmission system is the existence of reflected sound energy.

An impulse response can be obtain in several ways. One of them is using a diagram of waveform signal from the output of the measuring microphone at room impulse using several acoustic sources which produce a shot signal (Dirac impulse which is subjectively sensated as a shot, a gun, firecracker, piercing of the inflated balloon, electric spark etc.) [1]. Other ways are based on more sophisticated methods of measuring impulse response which are more precise and fully meet the requirements of the ISO 3382 standard [2]. These are methods which are based on the emission of complex incentive signals. Most frequently these are [3]: broadband, deterministic and recurring signal, eg *Maximum Length Sequence MLS* for system impulse which is believed to be linear and time invariable and sinusoidal signal with frequency which changes exponentially, logarithmic sweep signal, *SineSwap*, for system impulse which is not linear and also for time variable systems.

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Measuring of acoustic impulse response using *MLS* technique was first introduced by Schroeder in 1979 [4]. In 1995 Suzuki established „Optimum computer generated impulse signal“ [5]. In 2000 Farina introduced logarithmic SineSweep technique wit which he managed to overcome most of the limitations which at that time existed in the other techniques [6].

This paper analyzes the acoustic quality of a single room so that, based on impulse responses observed at multiple position of a microphone, following objective and subjective acoustic parameters are determined: *Reverberation Time*: T_{R20}, T_{R30} and T_{R60}; *Early Decay Time EDT*; *Centre Time* T_s; *Clarity*: C_{50} and C_{80}; *Definition*: D_{50} and D_{80} and rating of speech intelligibility: *Articulation Loss of Consonants* AL_{cons}, *Speech Transmission Index STI* and *Rapid Speech Transmission Index RASTI*. Diffusivity of a room is also tested using EDT/T_{30} ratio [7]. Obtained parameters values are analyzed compared to standard value and certain conclusions are given.

The organization of work is as follows. In section II the acoustic parameters of the room obtained from the acoustic impulse response are defined. In section III the experimental results and the analyses of the results for the acoustically treated room are shown. Section IV is the conclusion.

II. Acoustic Parameters of a Room

Following acoustic parameters are defined by ISO 3382 [2] i IEC 60268-16 standards [8]:

1) *Reverberation Time* T_{R60} (s), is the time necessary for decreasing of the sonic energy of a room, after turning off the sound source, to one millionth of its value compared to the steady state. Respectively, it is the time necessary for decreasing of the sound level, after turning off the sound source to 60dB compared to the sound level in steady state. T_{R60} is the same at all points of the room and it doesn't depend on either sound source or room geometry, but it is frequency dependant value.

Reverberation time T_{R60} (s), is defined in accordance to Sabin equation [1]:

$$T_R = \frac{0.16V}{A}, \quad (1)$$

and Eyring's equation [2]:

$$T_R = \frac{0.16V}{-S\,ln(1-\overline{\alpha})}, \quad (2)$$

where: V [m^3] is the total volume of a room; A [m^2]= $\overline{\alpha}\,S$ is the equivalent absorption area in a room; S [m^2] is the sum of all areas in a room; $\overline{\alpha}$ is the mean coefficient of the absorption. Sabin's formula is applicable for the rooms with the approximate diffuse sound field where T_R>0.8s, while Eyring's formula states more precision results for the rooms with T_R<0.8s.

During the measuring procedure it is not possible to achieve the dynamics of decline of the sound level in a room to 60dB, so that the reverberation is determined according to the decline of the sound level at 20dB, (T_{R20}), 25dB, (T_{R25}), 30dB, (T_{R30}).

Duration of the impulse response must be longer than the reverberation time. The dynamics of the measured impulse response must be at least 20dB, but it is recommended, for the sake of objectivity, that the dynamic range is at least 30dB [9].

2) *Early Decay Time*, *EDT*, is [10] defined as the time necessity for the sound level to decrease by 10dB, starting from -5dB compared to the maximum level. It depends on a room geometry. If *EDT* significantly deviates from the reverberation time, it is shown that it is most important for the subjective perception of a room reverberation.

3) *Centre Time* T_s, is a dimension which shows the discretely divides the impulse response into an early and a late period [7]. Along the timeline of the impulse response the values of this dimension give the information about equal energy of the initial part of the impulse response and the energy of the rest of the impulse response:

$$T_s = \int_0^\infty t h^2(t)dt \Big/ \int_0^\infty h^2(t)dt \,. \quad (3)$$

4) *Clarity* is the parameter which characterizes the time distinguishing tones which appear simultaneously despite the existing reverberation. The objective measure of the clarity is clarity index *C* [dB].The parameters C_{50} and C_{80} are defined as logarithmic relation of the early acoustic energy (the one which reaches the certain spot in the room for the first 50ms or 80ms of impulse response) to the remaining subsequent acoustic energy (the energy which appears after a defined moment in time):

$$C_{t_e} = 10 \log\left(\int_0^{t_e} h^2(t)dt \Big/ \int_{t_e}^\infty h^2(t)dt \right). \quad (4)$$

t_e is 50ms or 80ms. The parameter C_{50} is used for speech, and a C_{80} for music.

5) *Definition*, D_{50}, or D_{80}, represents the relation between the early acoustic energy (first 50ms or 80 ms of the impulse response) and the total acoustic energy ranging (0 - ∞):

$$D_{t_e} = \int_0^{t_e} h^2(t)dt \Big/ \int_0^\infty h^2(t)dt \,. \quad (5)$$

D_{t_e} also measures the share of the energy of a direct wave and early reflections within the total signal. It can be also shown as a percentage. The definition of the higher percentages provides better listening conditions, and significantly influences the intelligibility. The connection between the parameters D_{t_e} and C_{t_e} is achieved by the following relation:

$$C_{t_e} = 10 \log \frac{D_{t_e}}{1 - D_{t_e}} \,. \quad (6)$$

6) Speech intelligibility is performed using the objective parameters AL_{cons} (*Articulation Loss of Consonants*), *STI* (*Speech Transmission Index*) and *RASTI* (*Rapid Speech Transmission Index*) which qualify the subjective feeling of speech intelligibility. Peutz [10] explained that the percentage of indistinct consonants AL_{cons}. AL_{cons} depends on relation between the direct and the reflected sound, reverberation time, and the relation signal/noise in a room.

RASTI and *STIPA* (*Speech Transmission Index for Public address*) methods represent the condensed *STI* methods [8]. They are obtain by reducing the number of modulation frequencies and the number of octaves in which *STI* is calculated i.e. measured. *STIPA* is sensitive to the distortion in the system, and *RASTI* is focused on direct speech communication and it includes the impact of the environment.

III. Experimental Results and Analysis

A. The Experiment

The objective of the experiment is to establish the acoustic parameters of a room (teachers' office in the School of Mechanical Engineering '12. Februar' in Nis). Primarily the acoustic impulse responses are recorded, and then , using the software package Matlab both objective and subjective acoustic parameters are calculated. The decision on the suitability of a room is made using the comparative analysis of parameters values determined by ISO 3382 standard.

B. The Basis of the Acoustic Impulse Response

The recording of the acoustic impulse responses is carried out in the room shown in Fig. 1.

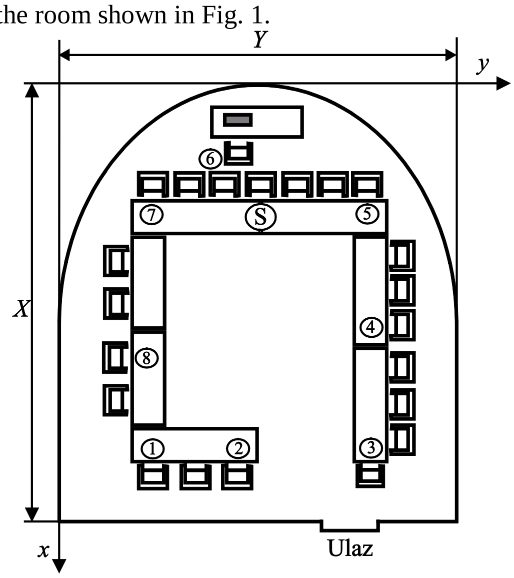

Fig. 1. The shew of the room where the impulse response is measured: S-the location of the sound source, 1 - 8 –the location of the receiver

Room dimensions are 9.9m × 9.8m × 3.6m. Room volume is $V = 312{,}1\text{m}^3$. A room may have up to 40 seats. The measuring of the impulse response is carried out using sweep incentive signal lasting 5s. The sampling frequency is f_s = 44.1kHz. The location of a sound source is S (2.64, 4.9, 1.3). The measurements are carried out at 8 measurement points: M1 (7.2,2.6, 1.3); M2 (7.2, 3.9, 1.3); M3 (7.2, 7.1, 1.3); M4 (4.84, 7.3, 1.3); M5 (2.64, 7.3, 1.3); M6 (1.55, 5.2, 1.3); M7 (2.64, 2.6, 1.3); M8 (4.57, 2.6,1.3). The reflective coefficients of the floor and ceiling walls are: 0.95, 0.95, 0.95, 0.95, 0.85 and 0.88.

C. The Results

The shew of the acoustic impulse responses of a room and the shew of Schroeder's curve (on the basis of which the reverberation time is determined) for 8 measured locations, are shown in Fig. 2 to 8. The obtained values of the acoustic parameters are shown in Table I (t is the arrival time of direct sound to the receiver).

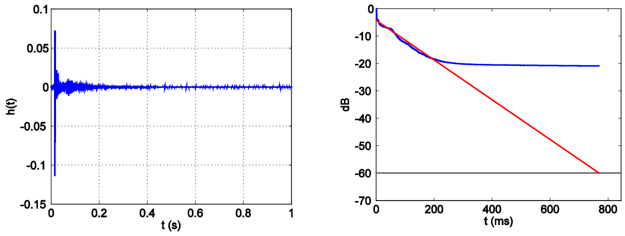

Fig. 2. The acoustic impulse response of a room and Schroeder's curve for the measured location 1

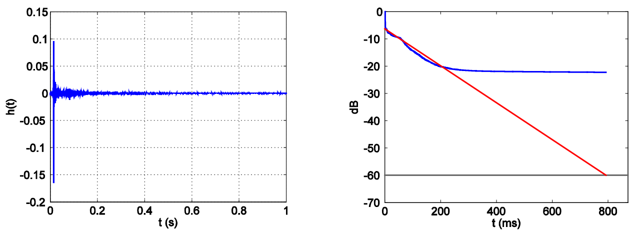

Fig. 3. The acoustic impulse response of a room and Schroeder's curve for the measured location 2

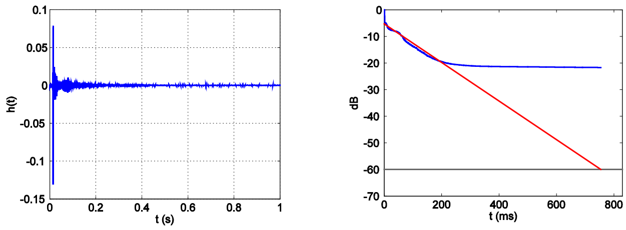

Fig. 4. The acoustic impulse response of a room and Schroeder's curve for the measured location 3

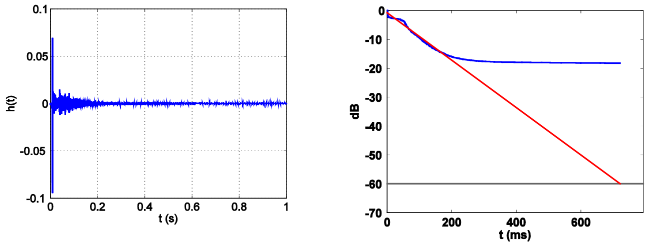

Fig. 5. The acoustic impulse response of a room and Schroeder's curve for the measured location 4

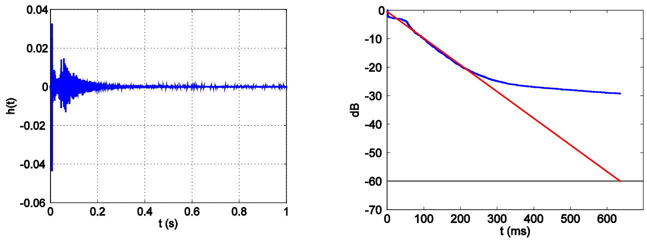

Fig. 6. The acoustic impulse response of a room and Schroeder's curve for the measured location 5

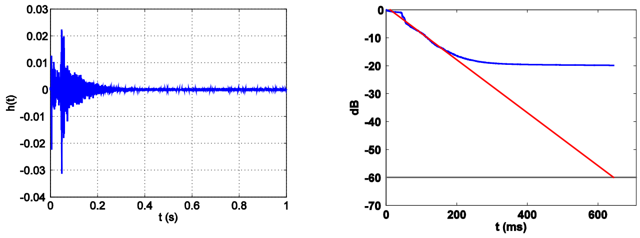

Fig. 7. The acoustic impulse response of a room and Schroeder's curve for the measured location 6

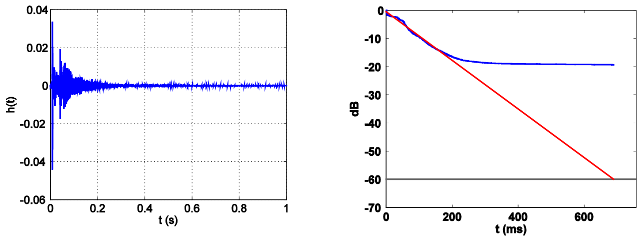

Fig. 8. The acoustic impulse response of a room and Schroeder's curve for the measured location 7

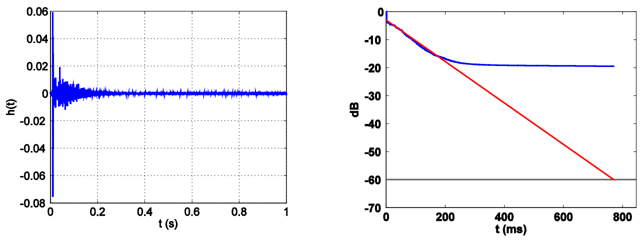

Fig. 9. The acoustic impulse response of a room and Schroeder's curve for the measured location 8

TABLE I
THE VALUES OF THE ACOUSTIC PARAMETERS OF THE ROOM.

Pos.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
***t* (ms)**	15.3	13.9	14.5	8.6	5.7	3.9	7.4	9.5
***EDT* (s)**	0.87	0.86	0.82	0.82	0.69	0.6	0.62	0.76
T_{20} (s)	0.22	0.2	0.2	0.23	0.27	0.22	0.23	0.23
T_{30} (s)	0.36	0.35	0.33	0.35	0.36	0.33	0.34	0.35
T_{60} (s)	0.77	0.79	0.75	0.76	0.72	0.64	0.69	0.77
$\frac{EDT}{T_{30}}$	2.42	2.49	2.48	2.31	1.92	1.82	1.82	2.17
T_c (ms)	43.6	30.1	35.2	50.2	83	87.3	76.5	59.1
C_{50} (dB)	6.49	9.0	7.96	6.17	1.27	- 0.24	1.57	5.53
C_{80} (dB)	10.7	12.5	12	9.57	7.16	5.87	7.38	8.76
D_{50} (%)	81.7	88.8	86.2	80.6	57.3	48.6	58.9	78.1
D_{80} (%)	92.2	94.7	94	90	83.8	79.4	84.6	88.3
STI	0.74	0.77	0.75	0.7	0.7	0.69	0.69	0.72
RASTI	0.75	0.81	0.78	0.71	0.68	0.63	0.7	0.72
AL_{cons} (%)	3.11	2.67	2.92	3.81	3.95	4.12	4.07	3.52

D. The Results Analysis

Based on the results shown in Fig. 2. to 9. and the Table I we can conclude the following:

1) The values during the reverberation time are within the following range T_{R60} = (0.64 - 0.79)s. The mean values of the reverberation time is $\overline{T}_{R60}$ = 0.74s. Considering that the optimal reverberation time for the rooms where speech prevails, with their volumes greater than 300m^3, with the range T_{R60} = (0.4 - 0.8)s, the measured reverberation time entirely meets the criteria. While measuring the reverberation time, using Sabin's model, T_{R60} = 0.6s is obtained, which is also within at above mentioned limits.

2) The relation EDT/T_{30} at medium frequencies is within the plan range EDT/T_{30} = 1.82 - 2.49. As the obtained values are not within the plan range EDT/T_{30} = 0.8 - 1.1, it means thet the measurements have been carried out in the space which is not diffusive.

3) The values of the definitions, D_{50}, and D_{80}, are higher than 50%. It confirms the excellent clarity of speech and bad clarity for the music in the room. Minimal deviation is for the measured location 6, D_{50} = 48.6%.

4) The centre time is T_s = (30-87.3)ms. Only the measured location 4, 7 and 8 meet the demands of T_s = (50-80)ms, which represent the integration constants for speech and music. Low values of the centre time for the measured locations 1, 2 and 3 indicate that most of the energy arrives in the initial part of the impulse response, which is related to the subjective feeling of the reverberation.

5) The value ranges for the speech transmission index *STI* and *RASTI* are *STI* = 0.69 - 0.77 and *RASTI* = 0.63 - 0.81. These values are within the range of determined values which represent good speech intelligibility: 0.6 - 0.75, and excellent speech intelligibility: values higher than 0.75.

6) The articulation loss of consonants, AL_{cons}, has values within the range of (2.67% - 4.12%) which belong to this parameter categorization AL_{cons} < 10% and indicate very good intelligibility (the ideal). The highest expected articulation loss of consonants, i.e. the weakest intelligibility (4.12%) is obtained for the measured location 6.

According to the conducted analyses of the results , we can draw the conclusion that the acoustic parameters of the analyzed room meet the conditions required by ISO 3382 standard for good speech intelligibility.

IV. CONCLUSION

The results of the measured acoustic parameters for the room which is used as teachers' office are shown in this study. Both objective and subjective parameters for rating of the room acoustics are defined. Based on the measured impulse responses of the room, both objective and subjective acoustic parameters are determined. The parameters are analysed in relation to the standard values determined by ISO 3382 standard for good speech intelligibility which concludes that: the mean values of reverberation time $0.4\text{s} \le \overline{T}_{R60} = 0.74\text{s} \le 0.8\text{s}$, the mean value of speech clarity index $\overline{C}_{50} = 4.72\text{dB} \ge -0.2\text{dB}$, articulation loss of consonants index $\overline{AL}_{cons}$ = 3.52% $\le$ 10%. According to the above shown results and their comparison to the standard values for the rooms intended for speech, we can draw the conclusion that the analyzed room is acoustically suitable for meetings.

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