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# METHOD OF EVALUATING THE QUALITY OF ROOM ACOUSTICS BASED ON ENERGY RELATIONS OF SOUND

# METODA EVALUACIJE KVALITETE AKUSTIKE SOBE TEMELJENOJ NA ENERGETSKIM RELACIJAMA ZVUKA

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Professional paper

***Abstract:*** *Measuring procedure of achieving room acoustic quality parameters with impulse response is usually used as the basis for acoustical measuring PC based software. The objective parameters: clarity (C), definition (D) and ratio between reflected and direct energy (R) are defined with reflected, direct and total energy of sound. The relations are set in order to enable estimation of other parameters based on measurement of only one energy parameter. Based on measurements in two architectural identical, but according to acoustic characteristics two different rooms, and additional analysis and calculations connected with number of people in a hall, objective parameters are evaluated according to earlier adopted optimal conditions involving certain deviations from the values.*

***Key words:*** *room acoustic, energy relations, sound, evaluation*

Stručni članak

***Sažetak:*** *Mjerni postupak postizanja parametara kvalitete zvuka prostorije impulsnim odzivom obično se koristi kao osnova za računalni software za akustično mjerenje. Jasnoća (C), definicija (D) i omjer između reflektirane i izravne energije (R) kao objektivni parametri definirani su reflektiranom, izravnom i ukupnom energijom zvuka. Odnosi su postavljeni tako da bi se omogućila procjena ostalih parametara na temelju mjerenja samo jednog parametra energije. Na temelju mjerenja u dvije arhitektonski identične, ali prema akustičnim svojstvima dvije različite prostorije te dodatnoj analizi i izračunima povezanima s brojem ljudi u dvorani, objektivni parametri se ocjenjuju prema ranije usvojenim optimalnim uvjetima koji uključuju određena odstupanja od vrijednosti.*

***Ključne riječi:*** *akustika sobe, energetske relacije, zvuk, evaluacija*

## 1. INTRODUCTION

The measurements were carried out using and omnidirectional speaker dodecaheadron as a sound source and the omnidirectional microphone Behringer ECM 8000. The test signal was MLS. Processing was done using Tascam US-144 soundcard and notebook with ARTA – Audio Measurement and Analysis Software. Acoustic descriptors are defined and formally recommended in standard ISO 3382 (Figure 7).

Measurement has been implemented with octave analysis of energy-time curves (ETC). Analysis of ETC was most appropriate because acoustic quality of room is mostly determined with flow of energy (reverberation time and early decay time (EDT) of sound energy and ratio between direct and reflected energy in reverberation. When ETC are measured, it is very important to look for time and frequency resolution of measurement results displaying. Two rooms with almost equal dimensions, but different acoustic properties were chosen for measurement and testing. Both rooms are in Department of Electroacoustic at the Faculty of Electrical Engineering and Computing, Zagreb, Croatia. One of the rooms is classroom without acoustical finishing, with volume of 270 m3, dimensions 11.95 m x 7.05 m x 3.20 m and it is used for lecturing. Detailed view of the room is shown on Figures 1, 2 and 3.

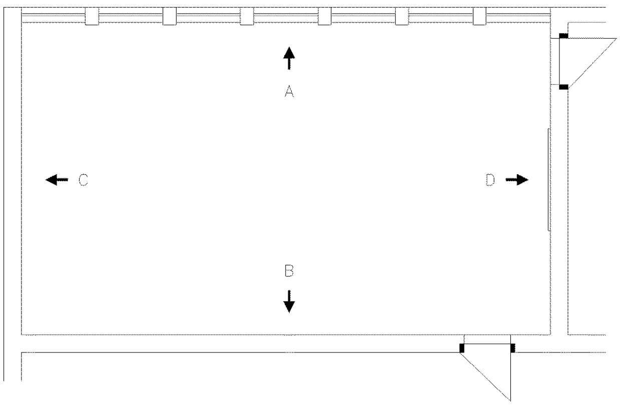


**Figure 1.** The groundplan of Room 1 – acousticaly untreated room

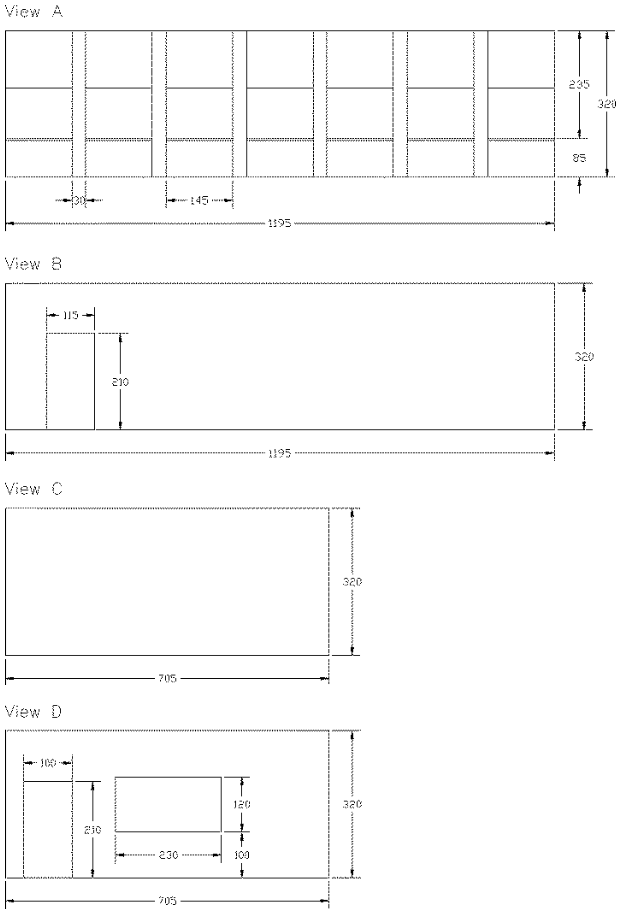


**Figure 2.** Dimensions of Room 1 - acousticaly untreated room

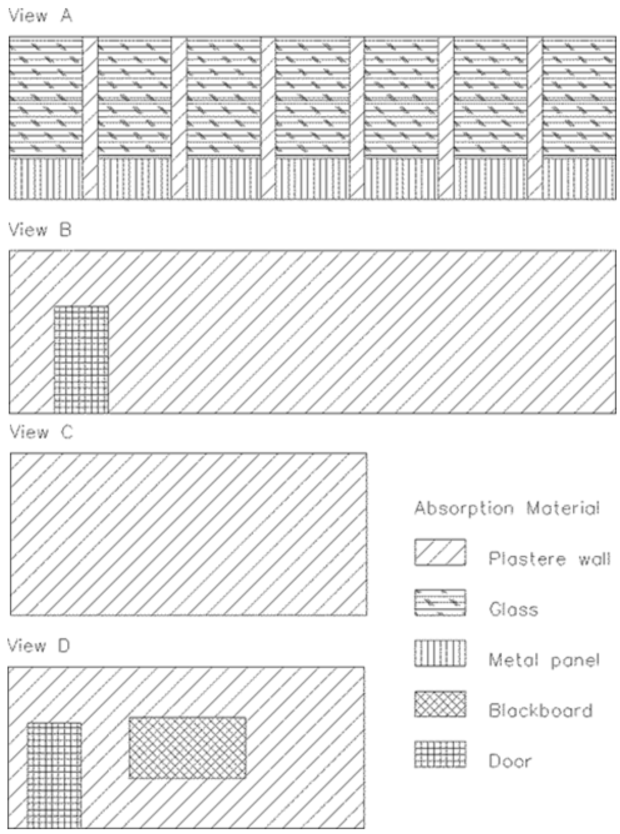


**Figure 3.** Layout of Room 1 with applied materials - acousticaly untreated room

Second room is approximately same dimensions, with volume of 230 m3, dimensions 10.20 m x 7.05 m x 3.20 m, but it is acoustically defined, and it is used as listening room, for parallel subjective testing of loudspeakers, psychoacoustic testing and recording. Detailed view of this room is shown on the Figures 4, 5 and 6. Absorption constructions (absorbers) are added in the room for purpose of acoustically finishing of this room. The room was measured in nine different points of the room. Area of auditorium was sampled in those points.

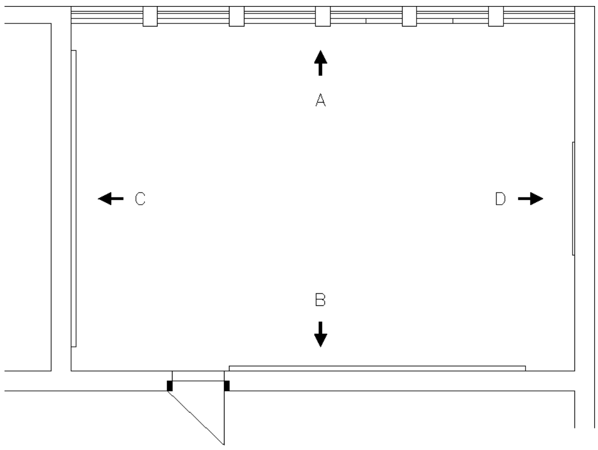


**Figure 4.** The groundplan of Room 2 – acousticaly treated room

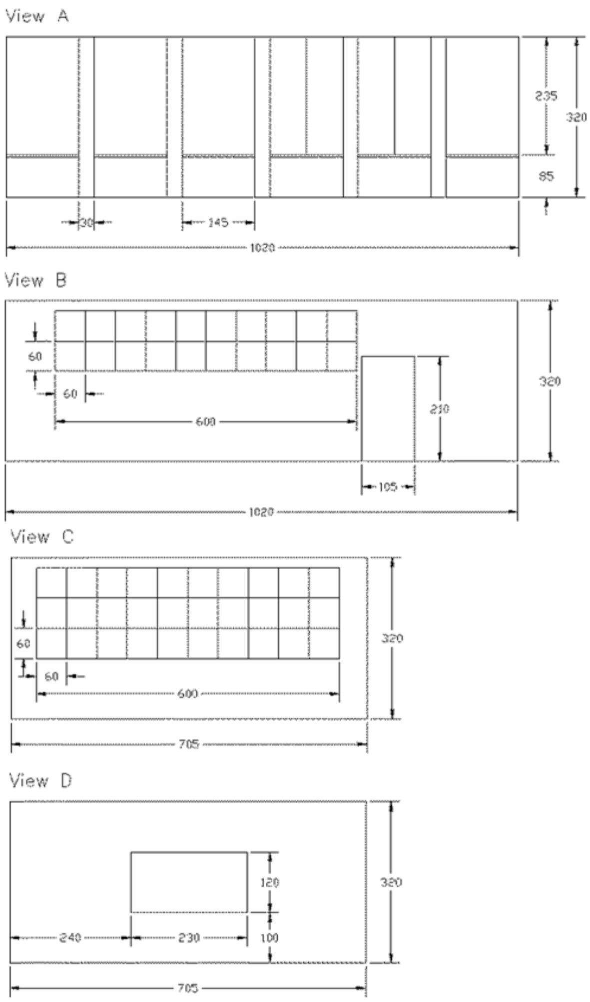


**Figure 5.** Dimensions of Room 2 - acousticaly treated room

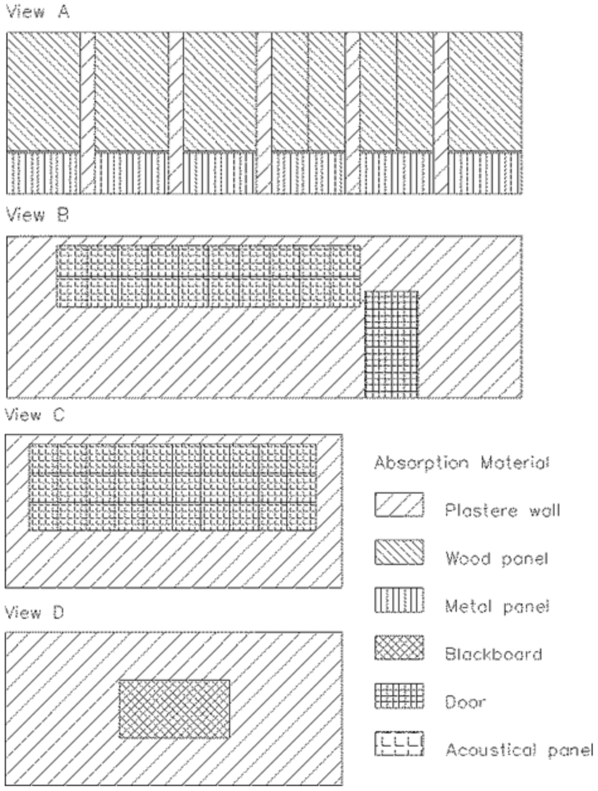


**Figure 6.** Layout of Room 2 with applied materials - acousticaly treated room

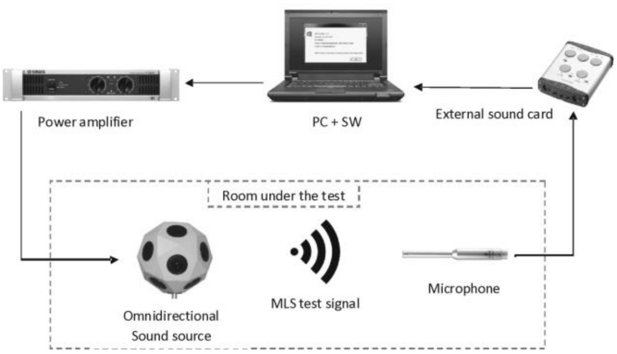


**Figure 7.** Measuring equipment layout

## 2. MEASUREMENT AND EVALUATION OF ENERGY RATIOS

Energy ratios of direct and reflected sound are responsible for acoustic properties of rooms. In 1953. Thiele suggested objective parameter of definition of sound D50 (as ratio of direct and total sound energy) and connected it with understanding of speech and definition of sound as subjective parameter of acoustic quality of room. In 1965 Beranek and Shultz suggested ratio between reflected and direct sound energy (R) and determinated influence on reverberation and movement as subjective parameters of acoustic quality. In 1975 Reichard and later Alim and Schmidt suggested clarity C (as ratio of direct and reflected energy of sound) and they determinated influence on clarity of music and brightness as subjective parameters of acoustic quality of room. Generally, energy of direct sound can be expressed

$$E_d(t_x) = k \cdot \int_0^{t_x} p^2(t)dt \quad (1)$$

and energy of reflected sound is given by equation:

$$E_r(t_x) = k \cdot \int_{t_x}^{\infty} p^2(t)dt \quad (2)$$

where is tx = 50 ms for speech or tx = 80 ms for music and k is coefficient of propotionality.

Thus definition of energy ratios can be written as in Table 1.that are common to all the people. Secondly, the components of human security are interdependent, which implies that it transgresses all types of borders. Further on, it is easier to ensure the human security by means of prevention. Finally, it is a concept that is people centered and is thus focused on the well-being of an individual in the society. “Like other fundamental concepts, human security is more easily identified through its absence than its presence.” The UNDP definition has to date remained one of the most widely accepted definitions despite the quite broad scope it includes.

**Table 1.** Definitions of energy ratios

| | C | D | R |
|---|---|---|---|
| $C_{t_x}$ | $\frac{E_d(t_x)}{E_r(t_x)}$ | $\frac{1}{\frac{1}{D_{t_x}}-1}$ | $\frac{1}{R_{t_x}}$ |
| $D_{t_x}$ | $\frac{1}{1+\frac{1}{C_{t_x}}}$ | $\frac{E_d(t_x)}{E_u}$ | $\frac{1}{1+R_{t_x}}$ |
| $R_{t_x}$ | $\frac{1}{C_{t_x}}$ | $\frac{1}{D_{t_x}}-1$ | $\frac{E_r(t_x)}{E_d(t_x)}$ |

Where total energy is:

$$E_u = E_d(t_x) + E_r(t_x) = k \cdot \int_0^{\infty} p^2(t)dt \quad (3)$$

This ratios can be expressed like relative ratios in dB. Energy of direct $E_d(t_x)$ and reflected sound $E_r(t_x)$ on different time distance ($t_x$ = 50 ms or $t_x$ = 80 ms in relation with time $t_x$ = 0 of direct incoming sound) are measured with methods based on integration ETC with octave frequency bandwidth. Octave values of measured energies are averaged values of measurements in all 9 measurement points. Considering recommended optimal values for objective parameters according different authors, modified method of valuing energy ratios was suggested, in the first order clarity C, which was suggested in 1996 by Marshall for evaluation speech $C_{50}$ and music $C_{80}$ .

Boundaries values of objective parameters for speech and music expressed like levels and their marks are shown in table 2.

**Table 2.** Evaluating objective parameters for speech and music

| $C_{80}$ | $D_{80}$ | $R_{80}$ | |
|---|---|---|---|
| +13 dB < $C_{80}$ | -0.21 dB < $D_{80}$ | $R_{80}$ < -13 dB | ⇒ 5 |
| +6 dB < $C_{80}$ ≤ +13 dB | -0.97 dB < $D_{80}$ ≤ -0.21 dB | -13 dB ≤ $R_{80}$ < -6 dB | ⇒ 4 |
| -6 dB ≤ $C_{80}$ ≤ +6 dB | -6.99 dB ≤ $D_{80}$ ≤ -0.97 dB | -6 dB ≤ $R_{80}$ ≤ +6 dB | ⇒ 3 |
| -13 dB ≤ $C_{80}$ <-6 dB | -13.22 dB < $D_{80}$ ≤ -6.99 dB | +6 dB < $R_{80}$ ≤ +13 dB | ⇒ 2 |
| $C_{80}$ < -13 dB | $D_{80}$ < -13.22 dB | +13 dB < $R_{80}$ | ⇒ 1 |

| $C_{50}$ | $D_{50}$ | $R_{50}$ | |
|---|---|---|---|
| +9 dB < $C_{50}$ | -0.52 dB < $D_{50}$ | $R_{50}$ < -9 dB | ⇒ 5 |
| +3 dB < $C_{50}$ ≤ +9 dB | -1.76 dB < $D_{50}$ ≤ -0.52 dB | -9 dB ≤ $R_{50}$ < -3 dB | ⇒ 4 |
| -3 dB ≤ $C_{50}$ ≤ +3 dB | -4.77 dB ≤ $D_{50}$ ≤ -1.76 dB | -3 dB ≤ $R_{50}$ ≤ +3 dB | ⇒ 3 |
| -9 dB ≤ $C_{50}$ <-3 dB | -9.39 dB < $D_{50}$ ≤ -4.77 dB | +3 dB < $R_{50}$ ≤ +9 dB | ⇒ 2 |
| $C_{50}$ < -9 dB | $D_{50}$ < -9.39 dB | +9 dB < $R_{50}$ | ⇒ 1 |

It can be seen that, if ratio of direct and reflected energy is known, all three values can be estimated. It is needed to consider measurements conditions and evaluations. Ratio of reflected energy with presence of auditorium ($E_{ri}$) and without presence of auditorium ($E_r$) are in ratio like reverberation time with presence ($T_{ri}$) and without presence of auditorium ($T_r$).

Reverberation time in same room, with same loudness depends of total absorption and it isn't same with auditorium and without it. Less absorption, more reverberation time and awry.

So it can be assumed next:

$$\frac{E_{ri}}{E_r} = \frac{T_{ri}}{T_r} \Rightarrow E_{ri} = \frac{T_{ri}}{T_r} E_r \qquad (4)$$

Analog with previous conclusions it can be assumed that ratio of direct energies with presence ($E_{di}$) and without presence of auditorium ($E_d$) are in relation as early decay time of sound energy with presence of people ($EDT_i$) and without presence of people (EDT) and it can be assumed next:

$$\frac{E_{di}}{E_d} = \frac{EDT_i}{EDT} \Rightarrow E_{di} = \frac{EDT_i}{EDT} E_d \qquad (5)$$

Thus, if ratios of energy are known with presence of auditorium, $C_i$, $D_i$, $R_i$, can be evaluated.

If only one parameter is known other two can be evaluated because of their correlation. Other two parameters can be easily estimated.

**Table 3.** Measured objective parameters in studio without presence of auditorium

| Frequency Hz | $C_{50}$ dB | $C_{80}$ dB | $D_{50}$ dB | $D_{80}$ dB | $R_{50}$ dB | $R_{80}$ dB |
|---|---|---|---|---|---|---|
| 63 | 4.57 | 9.08 | -1.30 | -0.51 | -4.57 | -9.08 |
| 125 | 5.46 | 9.79 | -1.09 | -0.43 | -5.46 | -9.79 |
| 250 | 8.19 | 10.82 | -0.61 | -0.35 | -8.19 | -10.82 |
| 500 | 8.29 | 11.70 | -0.60 | -0.28 | -8.29 | -11.70 |
| 1000 | 7.70 | 12.04 | -0.68 | -0.26 | -7.70 | -12.04 |
| 2000 | 7.78 | 12.73 | -0.67 | -0.23 | -7.78 | -12.73 |
| 4000 | 8.05 | 13.31 | -0.63 | -0.20 | -8.05 | -13.31 |
| 8000 | 13.24 | | -0.20 | | -13.24 | |

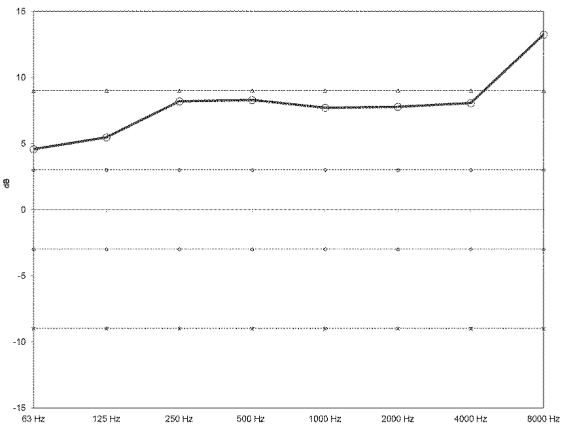


**Figure 8.** Clarity $C_{50}$ measured in studio without auditorium which evaluated values are given in Table 3 and average mark is 4

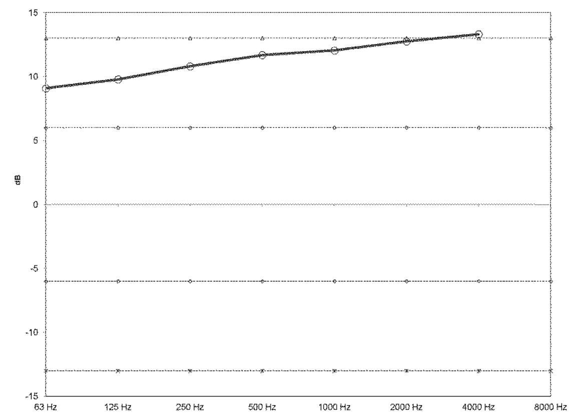


**Figure 9.** Clarity $C_{80}$ measured in studio without presence of auditorium which marks are given in table 3 and average mark is 4.

Table 4 shows marks $C_{50}$ and $C_{80}$ in studio which together give average mark of clarity C from 4.13, what is with subjective evaluating 4. The same mark is then for definition D and for ratio reflected-direct energy R.

**Table 4.** Marks $C_{50}$ and $C_{80}$ in studio

| Freq. | 63 Hz | 125 Hz | 250 Hz | 500 Hz | 1000 Hz | 2000 Hz | 4000 Hz | 8000 Hz |
|---|---|---|---|---|---|---|---|---|
| $C_{50}$ | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 |
| $C_{80}$ | 4 | 4 | 4 | 4 | 4 | 4 | 5 | |

**Table 5.** Evaluated objective parameters in studio with presence of auditorium

| Frequency Hz | $C_{50}$ dB | $C_{80}$ dB | $D_{50}$ dB | $D_{80}$ dB | $R_{50}$ dB | $R_{80}$ dB |
|---|---|---|---|---|---|---|
| 63 | 4.57 | 9.08 | -1.30 | -5.88 | -4.57 | 4.58 |
| 125 | 5.45 | 9.78 | -1.09 | -6.53 | -5.45 | 5.44 |
| 250 | 8.17 | 10.80 | -0.62 | -8.79 | -8.17 | 8.17 |
| 500 | 8.27 | 11.68 | -0.60 | -8.87 | -8.27 | 8.27 |
| 1000 | 7.70 | 12.04 | -0.68 | -8.38 | -7.70 | 7.70 |
| 2000 | 7.79 | 12.75 | -0.67 | -8.46 | -7.79 | 7.79 |
| 4000 | 8.05 | 13.31 | -0.63 | -8.68 | -8.05 | 8.05 |
| 8000 | 13.17 | | -0.20 | | -13.17 | |

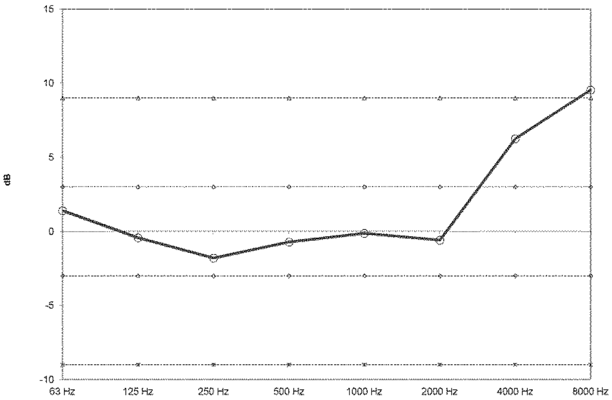


**Figure 10.** Clarity $C_{50}$ evaluated in studio included presence of auditorium which estimated values are given in table 5 and average mark is 4.

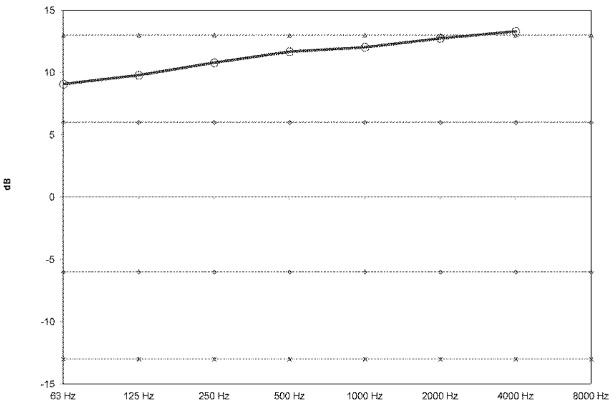


**Figure 11.** Clarity $C_{80}$ evaluated in studio included presence of auditorium which estimated values are given in table 5 and average mark is 4.

Table 6 shows marks of $C_{50}$ and $C_{80}$, which together give average mark of clarity C of 4.13 which is in order with subjective evaluating 4.

**Table 6.** Marks $C_{50}$ and $C_{80}$ in studio

| Freq. | 63 Hz | 125 Hz | 250 Hz | 500 Hz | 1000 Hz | 2000 Hz | 4000 Hz | 8000 Hz |
|---|---|---|---|---|---|---|---|---|
| $C_{50}$ | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 |
| $C_{80}$ | | 4 | 4 | 4 | 4 | 4 | 5 | |

**Table 7.** Measured objective parameters in seminar without presence of auditorium

| Frequency Hz | $C_{50}$ dB | $C_{80}$ dB | $D_{50}$ dB | $D_{80}$ dB | $R_{50}$ dB | $R_{80}$ dB |
|---|---|---|---|---|---|---|
| 63 | 1.40 | 3.94 | -2.36 | -1.47 | -1.40 | -3.94 |
| 125 | -0.43 | 1.20 | -3.23 | -2.45 | 0.43 | -1.20 |
| 250 | -1.80 | 0.20 | -4.00 | -2.91 | 1.80 | -0.20 |
| 500 | -0.76 | 1.11 | -3.41 | -2.49 | 0.76 | -1.11 |
| 1000 | -0.17 | 1.74 | -3.10 | -2.23 | 0.17 | -1.74 |
| 2000 | -0.60 | 1.64 | -3.32 | -2.27 | 0.60 | -1.64 |
| 4000 | 2.32 | 6.16 | -2.00 | -0.94 | -2.32 | -6.16 |
| 8000 | 9.68 | | -0.44 | | -9.68 | |

**Table 8.** Marks $C_{50}$ and $C_{80}$ in seminar without presence of auditorium

| Freq. | 63 Hz | 125 Hz | 250 Hz | 500 Hz | 1000 Hz | 2000 Hz | 4000 Hz | 8000 Hz |
|---|---|---|---|---|---|---|---|---|
| $C_{50}$ | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 5 |
| $C_{80}$ | 3 | 3 | 3 | 3 | 3 | 3 | 4 | |

**Table 9.** Evaluated objective parameters in seminar with presence of auditorium

| Frequency Hz | $C_{50}$ dB | $C_{80}$ dB | $D_{50}$ dB | $D_{80}$ dB | $R_{50}$ dB | $R_{80}$ dB |
|---|---|---|---|---|---|---|
| 63 | 1.39 | 3.93 | -2.37 | -3.76 | -1.39 | 1.39 |
| 125 | -0.44 | 1.19 | -3.23 | -2.80 | 0.44 | -0.44 |
| 250 | -1.81 | 0.18 | -4.01 | -2.20 | 1.81 | -1.82 |
| 500 | -0.73 | 1.15 | -3.39 | -2.66 | 0.73 | -0.72 |
| 1000 | -0.14 | 1.77 | -3.08 | -2.95 | 0.14 | -0.11 |
| 2000 | -0.60 | 1.65 | -3.32 | -2.72 | 0.60 | -0.60 |
| 4000 | 6.25 | 10.09 | -0.92 | -7.71 | -6.25 | 6.91 |
| 8000 | 9.54 | | -0.46 | | -9.54 | |

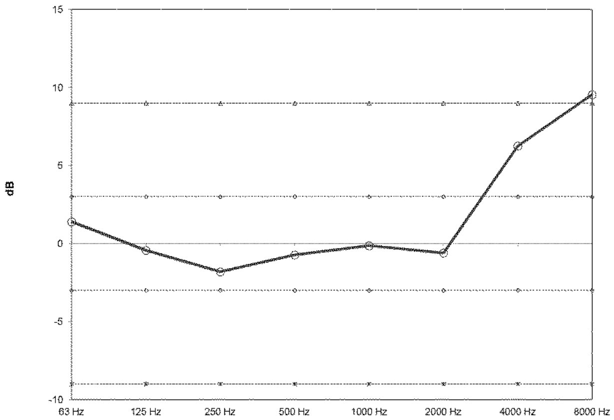


**Figure 12.** Clarity $C_{50}$ evaluated in seminar included in consideration presence of auditorium whose evaluated values are given in table 9 and average mark is 3

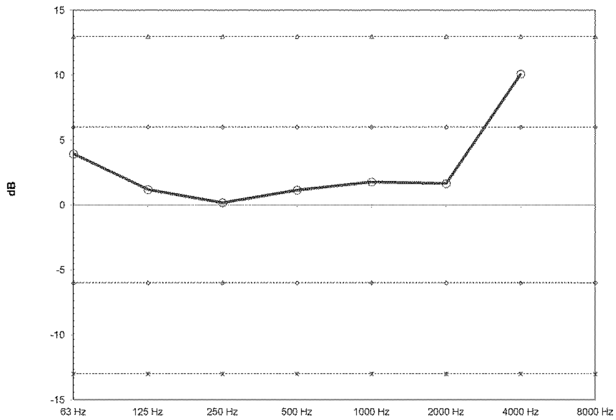


**Figure 13.** Clarity $C_{80}$ evaluated in seminar included in consideration presence of auditorium whose evaluated marks are given in table 9 and average mark is 3.

**Table 10.** Marks $C_{50}$ i $C_{80}$ in seminar

| Freq. | 63 Hz | 125 Hz | 250 Hz | 500 Hz | 1000 Hz | 2000 Hz | 4000 Hz | 8000 Hz |
|---|---|---|---|---|---|---|---|---|
| $C_{50}$ | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 5 |
| $C_{80}$ | 3 | 3 | 3 | 3 | 3 | 3 | 4 | |

## 3. CONCLUSION

Evaluation of acoustic quality of room is possible in the first order with direct subjective testing or indirect estimating objective measurement. Difficulties at evaluating acoustic quality of room are in defining subjective parameters acoustic quality of room, because they are generally expressed with description, while in analysis is needed to express them quantitative. Quantity expressing subjective parameters' is necessary for determine interdependency with objective parameters of acoustic quality of room. Comparing marks of objective parameters acoustic quality of room with different acoustic properties it is determined coincidence which confirms the validity of right assumption of measurement evaluation. This defined method of evaluating acoustic quality enable marking of subjective parameters acoustic quality based on marking measured objective parameters. This can be used at computer simulations of objective parameters in phase of projecting determinated room where with iterative method optimal acoustical quality is given according with acoustic properties of materials implemented in performance for special rooms, having in mind purpose of room. This like defined method of evaluating acoustic quality can be considered as background of implement standardizes quality of room.

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