

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

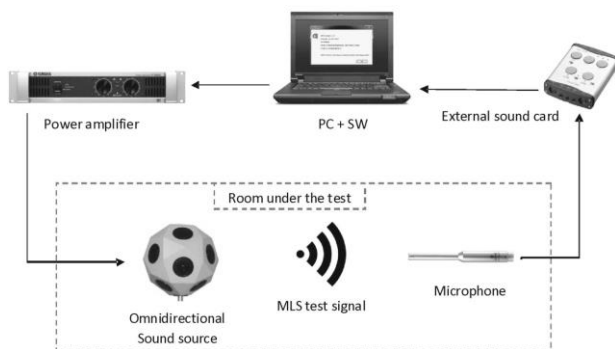


Figure 7. Measuring equipment layout

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 determined 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 determined 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 $t_x = 50$ ms for speech or $t_x = 80$ ms for music and k is coefficient of proportionality.

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:

$$\frac{E_{ri}}{E_r} = \frac{T_{ri}}{T_r} \Rightarrow E_{ri} = \frac{T_{ri}}{T_r} E_r \tag{4}$$

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:

$$\frac{E_{di}}{E_d} = \frac{EDT_i}{EDT} \Rightarrow E_{di} = \frac{EDT_i}{EDT} E_d \tag{5}$$

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	

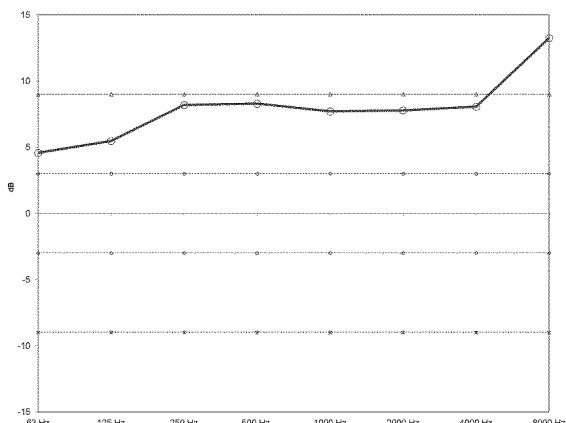


Figure 8. Clarity C₅₀ measured in studio without auditorium which evaluated values are given in Table 3 and average mark is 4

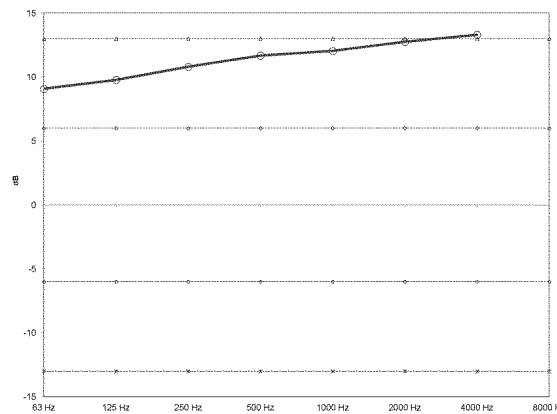


Figure 9. Clarity C₈₀ measured in studio without presence of auditorium which marks are given in table 3 and average mark is 4.

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	

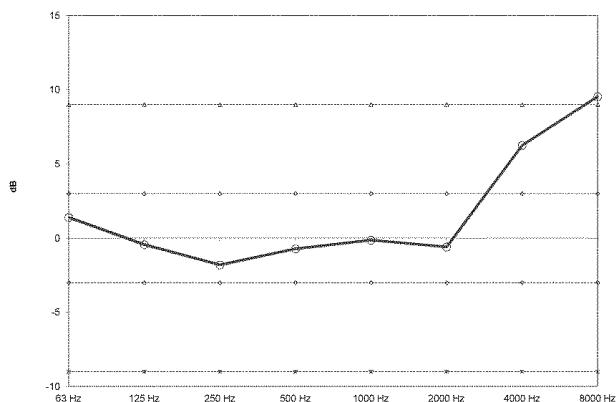


Figure 10. Clarity C_{50} evaluated in studio included presence of auditorium which estimated values are given in table 5 and average mark is 4.

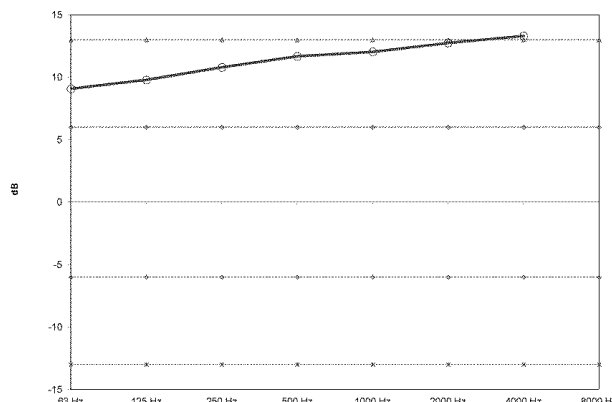


Figure 11. Clarity C_{80} evaluated in studio included presence of auditorium which estimated values are given in table 5 and average mark is 4.

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	

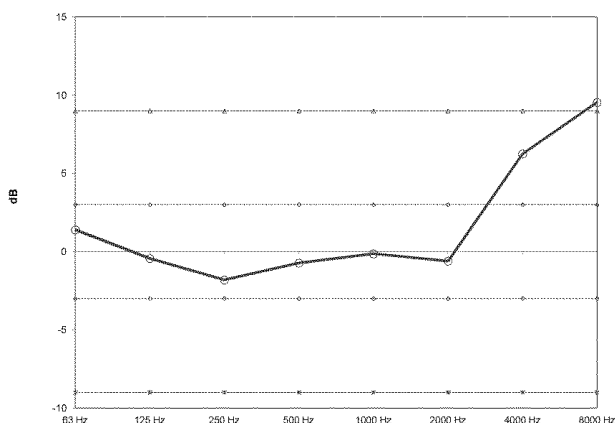


Figure 12. Clarity C_{50} evaluated in seminar included in consideration presence of auditorium whose evaluated values are given in table 9 and average mark is 3

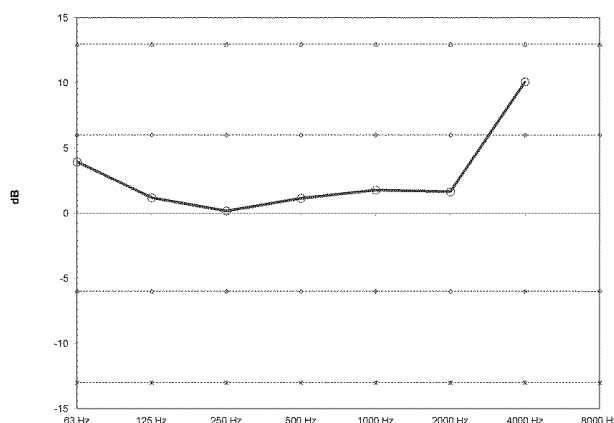


Figure 13. Clarity C_{80} evaluated in seminar included in consideration presence of auditorium whose evaluated marks are given in table 9 and average mark is 3.

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 determined 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.

4. REFERENCES

- [1] Abdou, R. W. Guy: Spatial information of sound fields for room-acoustic evaluation and diagnosis, The Journal of the Acoustical Society of America, USA, Vol. 100, No. 5, 1996.
- [2] Blauert, J.; Jekosch, U.: Sound-Quality Evaluation – A Multilayer Problem, Acoustica

- [3] Hirzel, S.: Verlag – Stuttgart, Volume 83, No. 5, 1997.
- [4] Fastl, H.: The Psychoacoustics of Sound-Quality Evaluation, Acoustica, S. Hirzel Verlag – Stuttgart, Volume 83, No. 5, 1997
- [5] Domitrović, H.; Fajt, S.; Krhen, M.: Multimedia Room Acoustical Design // Proceedings ELMAR-2009, Zadar : Croatian Society Electronics in Marine - ELMAR, Zadar, 2009. 221-224
- [6] Vodopija, J.; Fajt, S.; Krhen, M.: The influence of different source positions on acoustical parameters of churches // Proceedings of 1st EAA - Euroregio 2010.. Ljubljana, Slovenija, 2010.
- [7] Vodopija, J.; Fajt, S.; Krhen, M.: Evaluation of Acoustic Parameters of Churches // Proceedings of 10th French Congress of Acoustics. Lyon, Francuska, 2010.
- [8] Vodopija, J.; Fajt, S.; Krhen, M.: Assessment of Acoustic Properties of Churches // Proceedings of Inter Noise 2010. Lisbon, Portugal, 2010.

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