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PRINCIPAL COMPONENT ANALYSIS IN DETERMINING THE BEST SETUP FOR ACOUSTIC MEASUREMENTS IN SOUND CONTROL ROOMS

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Original scientific paper
Measuring process of acoustic quality parameters in sound control room in order to determine the best setup is described. Measurements of six sound control rooms impulse response have been made. The measurements are executed in accordance with the standard ISO3382. In all sound control rooms the same measurement method is used, but the measurement setups are changed. In the first scenario built-in monitor loudspeakers were used. In the second scenario, omnidirectional sound source was used. Omnidirectional measuring microphone and an artificial head were used as receivers. They were placed at the optimal listening position. Principal components analysis method is used to get the most accurate result from measured data obtained under different scenarios and measuring setups. Hence, the measuring conditions and setups which determine the value of subjective assessments of the sound control room are obtained. The results shall be used to calculate correlation between objective measurements and subjective assessments.

Keywords: *acoustic quality; acoustics; analytical method; objective parameters; principal component analysis; professional sound control room*

Metoda analize glavnih komponenenata u određivanju najboljih uvjeta akustičkih mjerenja tonskih režija

Izvorni znanstveni članak
Opisan je postupak mjerenja akustičke kvalitete u tonskim režijama, s ciljem utvrđivanja postavki koje daju najtočnije rezultate. Napravljena su mjerenja impulsnih odziva šest tonskih režija. Mjerenja su obavljena sukladno normi ISO3382. U svim tonskim režijama je upotrijebljena ista metoda, ali su mijenjani uvjeti mjerenja. U prvom slučaju korišteni su ugrađeni monitorski zvučnici. U drugom slučaju je korišten neusmjereni zvučni izvor. Neusmjereni mikrofon i umjetna glava su korišteni kao prijemnici. Oni su smješteni na optimalno mjesto za slušanje. Analiza glavnih komponenata je korištena za određivanje najtočnijih rezultata dobivenih uz različite uvjete mjerenja. Na taj način su dobiveni uvjeti mjerenja koji najbolje odgovaraju vrijednostima subjektivnih ocjena tonskih režija. Ti rezultati će biti korišteni za računanje korelacije između izmjerenih objektivnih i ocijenjenih subjektivnih parametara.

Ključne riječi: *akustička kvaliteta; akustika; analitička metoda; analiza glavnih komponenata; objektivni parametri; profesionalna tonska režija*

1 Introduction

Impulse response measurement method is one of the basic measurement methods in the field of objective acoustical study of the room [1]. Since a linear part of transfer function between two points in the room is considered, it is assumed that principles valid for linear systems are automatically applied to acoustic room measurements. Analysis of the energy in the room is usually performed at a constant percentage bandwidth, generally an octave or one-third of octave. The problem with impulse measurement of the room is to achieve an adequate signal to noise ratio, which results in praxis with application of several ways of acoustical impulse measurements of the room.

2 Methods for measuring the objective parameters of acoustical quality of the room

Objective measured data are obtained by measuring the impulse response of the room, whereas measurements are executed with the use of a personal computer, i.e. the software package Easera [2, 3] which is in accordance with the standard of ISO3382. The frequency range is from 63 Hz to 8 kHz, with standard octave bands. The excitation signal with sweep frequency and Maximum Length Sequence Signal – MLS is used. The rooms are excited in two scenarios. In the first scenario the installed equipment and built-in monitor loudspeakers are used, separately the left monitor speaker and separately the right monitor speaker. In the second scenario omnidirectional sound source is used, which is placed in front of the monitor loudspeakers and in front of the optimal positions provided for listening, Fig. 1. The signal from the personal computer (which is the signal source) is directly connected to the output stage of the installed electroacoustic equipment. In such a way all devices for signal processing are bypassed and their eventual impact on the signal is eliminated. Although the final analysis is done in the frequency range determined with central frequency of octave bands from 63 Hz to 8 kHz, sweep tone is generated in the frequency range 0 Hz to 24 kHz. The omnidirectional sound source is selected as a reference sound source that is used in all areas. Thus, on the one hand, the influence of different sound sources on the measurement results of the acoustic parameters when comparing the results of measurements in different areas is avoided [4]. On the other hand, the use of reference omnidirectional sound source gives us the illustration of the impact of sound sources that are used in daily work in those sound control rooms on the measurement results [5, 6].

The measurements were made in two ways - one-channel and binaural measurements, i.e. with one measuring microphone and with an artificial head, which were set on the position and at height in the room corresponding to the usual position for listening, i.e. the optimal listening position. As it is desired to reduce the possible measurement error to a minimum, five measurement cycles are executed for each measured parameter, and the final result is the mean value of such five values for each measured parameter. Prior to start of the five measurement cycles one pre-testing measurement is executed to check whether equipment setup is properly prepared and ready to start with the measurement process. The duration of the test signal is 5,5 s, and the sampling frequency is 48 kHz. Thus, for each measured parameter 262 144 signal samples are obtained.

The microphone is placed at the height of 1,40 m from the floor, at the exact position of the "sound engineer". Artificial head was always in the same position relative to the sound source and the microphone is placed on the medial plane, at the height of the artificial ears [7].

The known problem in measuring of acoustic parameters is repeatability. Due to measurement errors and measurement uncertainties it is sometimes difficult to get exactly the same results even with exactly the same measuring conditions. The exact repeatability is even more difficult to obtain using different types of signals and measuring conditions. Therefore, in this research measurement conditions and the measurement signals which will give the most accurate result are determined. Thus, good measurements repeatability is also obtained. This has been achieved with here shown and described measurement conditions and the applied excitation signal. Finally, the results were analysed using PCA method.

Therefore, the same measurement conditions in all rooms for all parameters are selected, as described above.

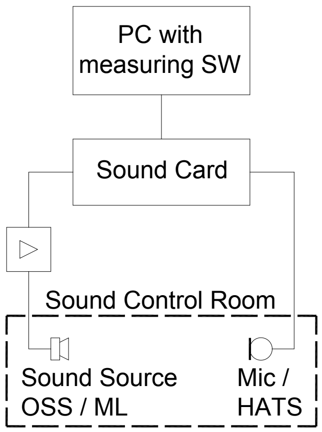

Figure 1 Measurement setup
(OSS - Omnidirectional Sound Source; ML - Monitor Loudspeaker; HATS – Head and Torso Simulator)

The values of the following objective parameters of room acoustic quality are calculated in accordance with ISO3382 standard [8÷11]:

- Early Decay Time - EDT
- Reverberation Time - RT_{10}, RT_{20}, RT_{30}
- Definition - D
- Clarity – C_7, C_{35}, C_{50}, C_{80}
- Inter Aural Cross Correlation Index – $IACC_{Early}$, $IACC_{Late}$ and $IACC_{Full}$

3 Analysis of sound control room objective parameters of acoustic quality

Research and analysis of the measured objective parameters of acoustic quality of the room were made for a total of six radio sound control rooms of Croatian Radiotelevision (Prisavlje 3, 10000 Zagreb), as follows:

- Sound Control Room R1 and R4 – multichannel music control room
- Control room R5 – speech and music control room
- Sound Control Room R13 – control room for audio editing
- Sound Control Room R11 – large control room of "Studio Bajsić"
- Sound Control Room R12 – small control room of "Studio Bajsić".

Listed professional sound control rooms have a minimum floor area of 25,9 m^2 to a maximum of 46,20 m^2, with a corresponding volume of at least 75,11 m^3 to a maximum of 157,08 m^3, which is consistent with standardized sizes of the average professional sound control rooms. All rooms are appropriately acoustically treated, i.e. insulated walls to protect from outside noise, separated with a window from the studio area and are equipped with special doors that meet the needs of acoustic insulation from outside noise. In each room a mixing console is placed on the best listening position, and sound is radiated through professional loudspeaker systems [12].

Analysis of the measured objective parameters of acoustic quality of sound control room includes analysis of the results across measured frequency band. It includes the range of octave bands with central frequencies from 125 Hz to 8 kHz. With the statistical method Principal Component Analysis (PCA) measurement setup conditions are determined, for which the most accurate measurement results are obtained.

PCA is a statistical method, described in detail in [13], [14] which combines a large number of variables (results) to new, virtual variables called principal components. Those variables incorporate all existing and actually measured values, but their number is far lower than the actual. The method of calculating the principal components includes getting the data, subtracting the mean, calculating the covariance matrix, calculating the eigenvectors and eigenvalues of the covariance matrix, choosing components and forming a feature vector, and finaly, deriving the new data set [13]. In this analysis, the number of principal components is limited to two (Principal Component One - PC1 and Principal Component Two - PC2) and it is found which actual measured parameters and measurement conditions have the greatest effect on the two selected (first two) components. Selecting those two principal components only the biggest impact of actual results is analysed. Also, a further increase in the number of observed principal components would increase the complexity of the analysis and at the same time, their influence on the results is not significant.

The above principle enables to determine conditions necessary to measure the acoustic properties of the room in the best way. It is assumed that every measured room meets the requirements required for analysis, and they are: all variables were measured under the same conditions, the amplitude of excitation area is such that there is a linear relationship between the variables, the number of samples is large enough to be assumed they fairly represent the corresponding measured value, all data are suitable for analysis, and no inappropriate deviations occurs in results. Mentioned inappropriate deviations in measurement results are also monitored during the measurements.

Objective parameters are measured in each room nine times with nine different conditions. For the purpose of mathematical analysis each condition of measurement is indicated by a special label, as follows:

Sound Source:
OSS – Omnidirectional Sound Source
ML – Monitor Loudspeaker
Position in the room:
C – Centre
R – Right
L – Left
Sound Source Signal:
SW – Sweep Signal
MLS – Maximum Length Sequence Signal
Sweep:
Lin – Linear Sweep
Log – Logarithmic Sweep

Table 1 Measurements' conditions and labels for the statistical method of PCA

Source	OSS	OSS	OSS	ML	ML	ML	ML	ML	ML
Position	C	C	C	R	R	R	L	L	L
Signal	SW	SW	MLS	SW	SW	MLS	SW	SW	MLS
Sweep	Lin	Log	-	Lin	Log	-	Lin	Log	-
EDT	M1	M2	M3	M4	M5	M6	M7	M8	M9
RT10	M10	M11	M12	M13	M14	M15	M16	M17	M18
RT20	M19	M20	M21	M22	M23	M24	M25	M26	M27
RT30	M28	M29	M30	M31	M32	M33	M34	M35	M36
C_7	M1	M2	M3	M4	M5	M6	M7	M8	M9
C_{50}	M10	M11	M12	M13	M14	M15	M16	M17	M18
C_{80}	M19	M20	M21	M22	M23	M24	M25	M26	M27
C_{35}	M28	M29	M30	M31	M32	M33	M34	M35	M36
D	M1	M2	M3	M4	M5	M6	M7	M8	M9
$IACC_{Early}$	M1	M2	M3	M4	M5	M6	M7	M8	M9
$IACC_{Late}$	M10	M11	M12	M13	M14	M15	M16	M17	M18
$IACC_{Full}$	M19	M20	M21	M22	M23	M24	M25	M26	M27

Prior to making the PCA analysis, a statistical analysis of the results was made for each measured parameter of the sound control rooms, which includes:

- Mean value
- Lower bound of 95 % confidence interval for Mean
- Upper bound of 95 % confidence interval for Mean
- 5 % Trimmed Mean
- Median
- Variance
- Standard deviation
- Minimum value
- Maximum value
- Range.

As this is an extremely large amount of data, this paper presents only the results of PCA analysis, which are the goal of this research.

3.1 Multichannel music control room R1

Principal component analysis of the reverberation time measured values shows that the greatest impact on the first two principal components PC1 and PC2 for the parameter EDT have measurements M3 and M9; for the parameter RT_{10} have measurements M11 and M10; for the parameter RT_{20} have measurements M21 and M19, while for the parameter RT_{30} have measurements M36 and M32.

As in most cases the biggest impact on the first two principal components have measurements performed using an omnidirectional sound source, it can be concluded that the results of the reverberation time measurements made with omnidirectional sound source give the results that best suit their actual values.

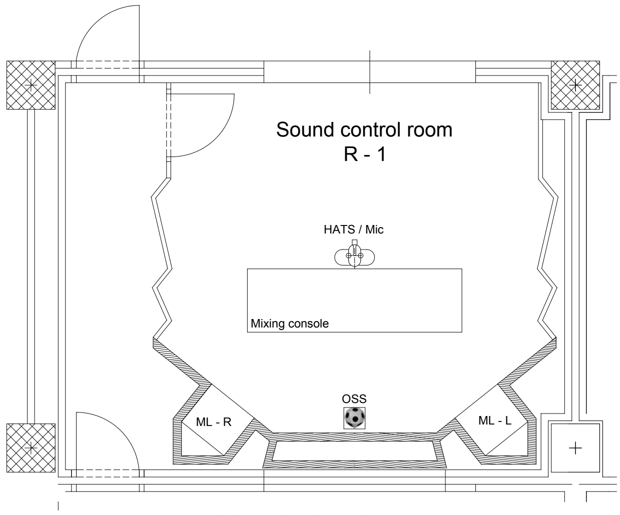

Figure 2 Layout of the multichannel music control room R1

Table 2 Construction parameters of the multichannel music control room R1

Width / m	Depth / m	Height / m	Floor area / m^2	Volume / m^3
6,00	5,80	2,90	35,50	102,95

Principal component analysis of the Clarity C measured values, parameter C_7 indicates that the greatest impact on the first two principal components PC1 and PC2 have measurements M5 and M8; for the parameter C_{50} have measurements M13 and M14; for the parameter C_{80} have measurements M25 and M26, while for the parameter C_{35} have measurements M31 and M33.

As in all cases the greatest impact in the first two principal components have measurements obtained with monitor loudspeakers excited with sweep signal, it can be concluded that this measurement conditions give results that best suit their actual values. Additionally during the calculation of the principal components related to the Clarity C, no significant impact on the measurements with omnidirectional sound source is noticed.

Principal component analysis of the Definition D values indicates that the greatest impact on the first two principal components PC1 and PC2 have measurements M4 and M5.

Principal component analysis of the interaural cross-correlation coefficient IACC values shows that the first two principal components PC1 and PC2 for parameter $IACC_{Early}$ are mainly defined by measurements M3 and M1; for parameter measurements $IACC_{Late}$ by measurements M13 and M9, and the overall coefficient $IACC_{Full}$ by measurements M19 and M17.

Clearly, measurements carried out with omnidirectional sound source have a significant impact on the determination of the first two principal components for IACC coefficient.

Table 3 Coefficients of principal components of the objective room quality parameters for the multichannel music control room R1

Parameter	Measurement	Principal component	
		PC1	PC2
EDT	M3	0,918	0,372
	M9	0,907	0,377
RT_{10}	M11	0,964	−0,235
	M10	0,957	−0,120
RT_{20}	M21	0,949	−0,142
	M19	0,932	0,276
RT_{30}	M36	0,991	0,120
	M32	0,989	−0,105
C_7	M5	0,994	
	M8	0,993	
C_{50}	M13	0,951	−0,247
	M14	0,948	−0,270
C_{80}	M25	0,907	−0,369
	M26	0,898	−0,338
C_{35}	M31	0,929	−0,303
	M33	0,920	−0,324
D	M4	0,963	0,197
	M5	0,960	0,232
$IACC_{Early}$	M3	0,980	−0,112
	M1	0,979	−0,161
$IACC_{Late}$	M13	0,993	
	M9	0,987	
$IACC_{Full}$	M19	0,980	−0,113
	M17	0,980	−0,160

3.2 Multichannel music control room R4

Principal component analysis of the reverberation time values shows that the greatest impact on the first two principal components PC1 and PC2 for parameter EDT have measurements M8 and M9; for the parameter RT_{10} have measurements M16 and M17; for the parameter RT_{20} have measurements M21 and M23, while for the parameter RT_{30} have measurements M31 and M35.

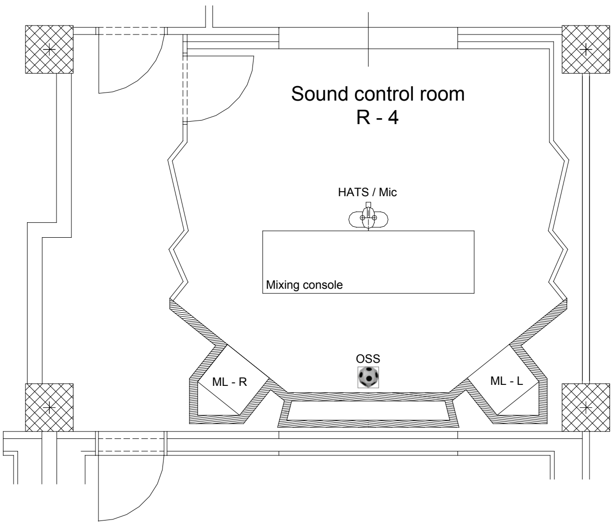

Figure 3 Layout of the multichannel music control room R4

Table 4 Construction parameters of the multichannel music control room R4

Width / m	Depth / m	Height / m	Floor area / m^2	Volume / m^3
6,00	5,80	2,90	35,50	102,95

As in most cases the biggest impact on the first two principal components have measurements performed using built-in speakers, it can be concluded that the results of the reverberation time measurement facilitated by built-in speakers and excited with sweep tone, give results that best match their actual values.

Principal component analysis of the Clarity C values in the multichannel music control room R4, parameter C_7 indicates that the greatest impact on the first two principal components PC1 and PC2 have measurements M9 and M7; for the parameter C_{50} have measurements M15 and M13; for the parameter C_{80} have measurements M24 and M25, while for the parameter C_{35} have measurements M34 and M35.

Table 5. Coefficients of principal components of the objective room quality parameters for the multichannel music control room R4

Parameter	Measurement	Principal component	
		PC1	PC2
EDT	M8	0,946	−0,113
	M9	0,925	−0,128
RT_{10}	M16	0,990	
	M17	0,987	
RT_{20}	M21	0,992	
	M23	0,986	−0,147
RT_{30}	M31	0,988	−0,135
	M35	0,981	−0,186
C_7	M9	0,995	
	M7	0,995	
C_{50}	M15	0,995	
	M13	0,995	
C_{80}	M24	0,977	−0,146
	M25	0,977	−0,178
C_{35}	M34	0,970	−0,207
	M35	0,967	−0,239
D	M4	0,996	
	M6	0,995	
$IACC_{Early}$	M8	0,962	
	M7	0,962	
$IACC_{Late}$	M14	0,984	
	M13	0,983	
$IACC_{Full}$	M26	0,969	
	M25	0,964	−0,130

As in all cases the greatest impact on the first two principal components have measurements facilitated by monitor loudspeakers and excited with sweep signal, it can be concluded that this measurement conditions will produce results that most closely match their actual values. Additionally, during the calculation of the principal components related to the clarity C, no significant impact of measurements done with omnidirectional sound source is noticed.

Principal component analysis of the Definition D values indicates that the greatest impact on the first two principal components PC1 and PC2 have measurements M4 and M6.

Principal component analysis of the interaural cross-correlation coefficient IACC values shows that the first two principal components PC1 and PC2 for parameter $IACC_{Early}$ are mainly defined by measurements M8 and M7; for parameter by $IACC_{Late}$ measurements M14 and M13, and the overall coefficient $IACC_{Full}$ by M26 and M25.

Clearly, measurements done with built-in monitor loudspeakers have a dominant impact on the calculation of the first two principal components for IACC coefficient for sound control room R4.

3.3 Speech and music control room R5

Principal component analysis of the reverberation time values EDT shows that the greatest impact on the first two principal components PC1 and PC2 for parameter EDT have measurements M1 and M6; for the parameter RT_{10} have measurements M11 and M18; for the parameter RT_{20} have measurements M26 and M27, while for the parameter RT_{30} measurements M35 and M33.

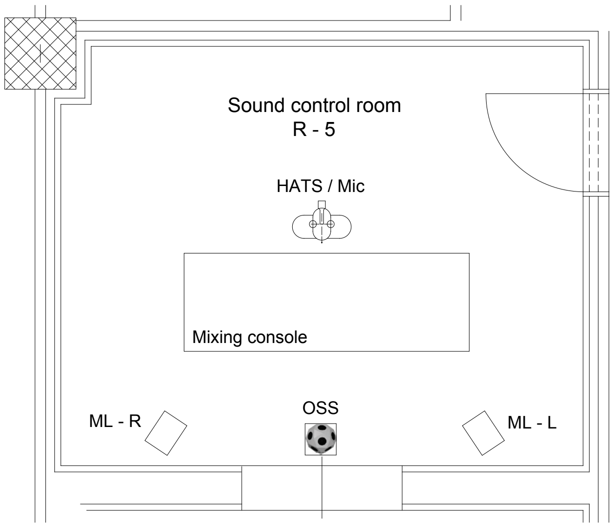

Figure 4 Layout of the speech and music control room R5

Table 6 Construction parameters of the speech and music control room R5

Width / m	Depth / m	Height / m	Floor area / m^2	Volume / m^3
5,86	4,70	2,90	27,80	80,62

It is important that in the sound control room R5, a measurement executed with omnidirectional sound source has the greatest impact on the first principal component PC1 for the measured values of parameters EDT andRT_{10}, while measurement executed with build-in control monitor primarily effects measurement of parameters RT_{20} and RT_{30}. As the second principal component PC2 is determined by measurements done with monitor speakers in all cases, it can be stated that the results of reverberation time measurements will be most accurate in cases when monitor loudspeakers are used.

Principal component analysis of the Clarity C values in the speech and music control room R5 indicates that the greatest impact on the first two principal components PC1 and PC2 for parameter C_7 have measurements M5 and M6; for the parameter C_{50} have measurements M15 and M14; for the parameter C_{80} have measurements M23 and M22, while for the parameter C_{35} have measurements M33 and M32.

Principal component analysis of the parameter clarity C measurement results in sound control room R5 shows in all cases that the biggest impact on the first two principal components PC1 and PC2 occurred when room was excited with right-hand control monitor. Therefore, it can be concluded for room R5 that the best results are obtained with measurements performed with control monitor loudspeaker, and specifically in this case the right-hand one.

Principal component analysis of the Definition D values indicates that the greatest impact on the first two principal components PC1 and PC2 have measurements M6 and M5.

Principal component analysis of the interaural cross-correlation coefficient IACC values shows that the first two principal components PC1 and PC2 are mainly defined for parameter $IACC_{Early}$ by measurements M5 and M6; for parameter measurements $IACC_{Late}$ by M10 and M15, and the overall coefficient $IACC_{Full}$ by M23 and M24.

Clearly, measurements carried out with control monitor, especially with the right-hand monitor, have the most significant effect on the calculation of the first two principal components for the IACC coefficient. Only in one case a significant impact on the principal components PC1 and PC2 have measurements with omnidirectional sound source.

Table 7 Coefficients of principal components of the of objective room quality parameters for the speech and music control room R5

Parameter	Measurement	Principal component	
		PC1	PC2
EDT	M1	0,956	0,135
	M6	0,956	−0,142
RT_{10}	M11	0,985	−0,112
	M18	0,975	0,150
RT_{20}	M26	0,972	−0,159
	M27	0,965	−0,190
RT_{30}	M35	0,979	−0,178
	M33	0,973	0,189
C_7	M5	0,960	0,108
	M6	0,956	
C_{50}	M15	0,971	
	M14	0,935	−0,197
C_{80}	M23	0,968	
	M22	0,963	
C_{35}	M33	0,992	
	M32	0,977	−0,153
D	M6	0,971	
	M5	0,928	−0,152
$IACC_{Early}$	M5	0,972	
	M6	0,967	
$IACC_{Late}$	M23	0,978	
	M24	0,975	
$IACC_{Full}$	M23	0,978	
	M24	0,975	

3.4 Control room for audio editing R13

Principal component analysis of the reverberation time values shows that the greatest impact on the first two principal components PC1 and PC2 for parameter EDT have measurements M7 and M9; for the parameter RT_{10} have measurements M11 and M10; for the parameter RT_{20} have measurements M24 and M22, while for the parameter RT_{30} measurements M31 and M30.

The impact on the first two principal components PC1 and PC2 in this case have the measurements carried out by omnidirectional sound source, as well as measurements with monitor loudspeakers, depending on the measured dynamics range. It is interesting that the biggest impact on measurements with omnidirectional sound source is for the parameter RT_{10}, where the dynamics is the smallest. Although there is the impact on the results obtained from excitation with MLS signal, in most cases more significant is excitation with sweep tone.

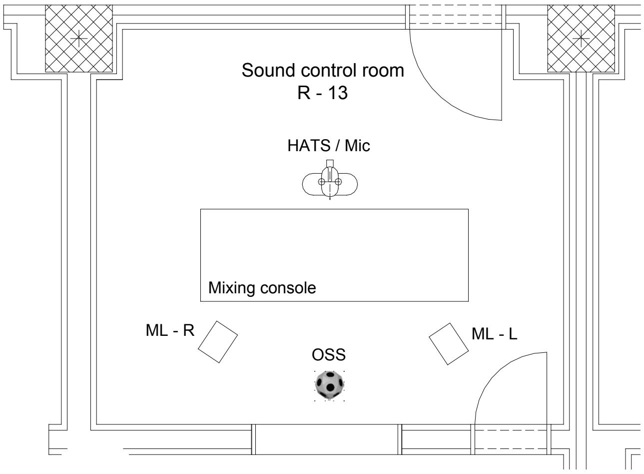

Figure 5 Layout of the control room for audio editing R13

Table 8 Construction parameters of the control room for audio editing R13

Width [m]	Depth [m]	Height [m]	Floor area [m²]	Volume [m³]
5,58	4,71	2,90	25,90	75,11

Principal component analysis of the Clarity C values in the control room for audio editing R13, parameter C_7 indicates that the greatest impact on the first two principal components PC1 and PC2 have measurements M7 and M8; for the parameter C_{50} have measurements M15 and M13; for the parameter C_{80} have measurements M25 and M26, while for the parameter C_{35} have measurements M28 and M29.

Table 9 Coefficients of principal components of objective room quality parameters for the control room for audio editing R13

Parameter	Measurement	Principal component	
		PC1	PC2
EDT	M7	0,976	−0,179
	M9	0,976	
RT_{10}	M11	0,982	
	M10	0,955	
RT_{20}	M24	0,955	−0,128
	M22	0,952	
RT_{30}	M31	0,985	0,143
	M30	0,977	
C_7	M7	0,963	0,190
	M8	0,958	0,216
C_{50}	M15	0,973	0,107
	M13	0,964	
C_{80}	M25	0,983	0,122
	M26	0,980	0,144
C_{35}	M28	0,975	
	M29	0,970	
D	M4	0,981	−0,105
	M5	0,979	−0,109
$IACC_{Early}$	M8	0,956	−0,117
	M9	0,949	−0,127
$IACC_{Late}$	M14	0,982	−0,136
	M10	0,972	
$IACC_{Full}$	M26	0,956	−0,112
	M27	0,949	−0,122

The principal components in the case of control room R13 in most cases are determined by measurements performed with excitation via the monitor speakers. Only the results of measurements carried out by omnidirectional sound source of the parameter C_{35} have significant impact on the first two principal components PC1 and PC1.

Principal component analysis of the Definition D values indicates that the greatest impact on the first two principal components PC1 and PC2 have measurements M4 and M5.

Principal component analysis of the interaural cross-correlation coefficient IACC values shows that the first two principal components PC1 and PC2 are mainly defined for parameter $IACC_{Early}$ by measurements M8 and M9; for parameter measurements $IACC_{Late}$ by M14 and M10, and the overall coefficient $IACC_{Full}$ M26 and M27.

Clearly, measurements taken with monitor loudspeakers significantly impact the calculation of the first two principal components for IACC coefficient.

3.5 Large control room of "Studio Bajsić" R11

Principal component analysis of the reverberation time values shows that the greatest impact on the first two principal components PC1 and PC2 for parameter EDT have measurements M8 and M9; for the parameter RT_{10} have measurements M16 and M17; for the parameter RT_{20} have measurements M21 and M26, while for the parameter RT_{30} have measurements M33 and M35.

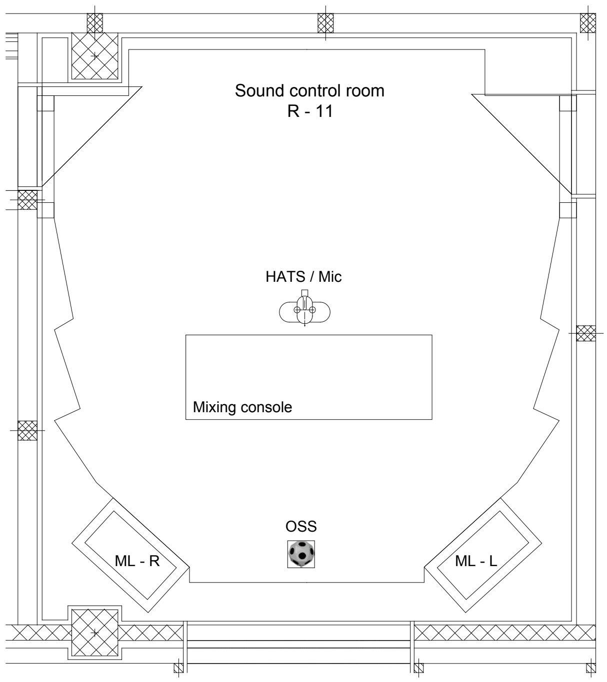

Figure 6 Layout of the large control room of "Studio Bajsić" R11

Table 10 Construction parameters of the large control room of "Studio Bajsić" R11

Width / m	Depth / m	Height / m	Floor area / m²	Volume / m³
6,60	7,00	3,40	46,20	157,08

Analysis and definition of the first two principal components PC1 and PC2 for control room R11 shows that in most cases a significant impact have measurements with monitor loudspeakers, mostly right-hand speaker. There is only one case with a significant impact of measurements with omnidirectional sound source. In most cases significant impact has the sweep signal.

Principal component analysis of the Clarity C values in the large control room of "Studio Bajsić" R11indicates that the greatest impact on the first two principal components PC1 and PC2 for parameter C_7 have measurements M5 and M4; for the parameter C_{50} have measurements M14 and M13; for the parameter C_{80} have measurements M24 and M22, while for the parameter C_{35} have measurements M31 and M33.

Calculating process of the principal components PC1 and PC2 for the measurement of sound control room R11 related to the parameter Clarity shows that the biggest impact on results have measurements carried out with the right-hand control monitor and in most cases with sweep tone. There is no case where measurements carried out by omnidirectional sound source have big significance for principal components PC1 and PC2.

Principal component analysis of the Definition D values indicates that the greatest impact on the first two principal components PC1 and PC2 have measurements M4 and M5.

Also in case of parameter Definition D, a significant impact on the calculation of the first two principal components PC1 and PC2 have measurements done with right-hand control monitor.

Principal component analysis of the interaural cross-correlation coefficient IACC values shows that the first two principal components PC1 and PC2 are mainly defined for parameter $IACC_{Early}$ by measurements M7 and M9; for parameter measurements $IACC_{Late}$ by M13 and M14, and the overall coefficient $IACC_{Full}$ by M25 and M27.

Clearly, measurements taken with control monitor have a significant impact in the calculation of the first two principal components for IACC coefficient.

Table 11 Coefficients of principal components of the of objective room quality parameters for the large control room of "Studio Bajsić" R11

Parameter	Measurement	Principal component	
		PC1	PC2
EDT	M8	0,987	
	M9	0,983	0,106
RT_{10}	M16	0,970	0,156
	M17	0,959	0,177
RT_{20}	M21	0,923	0,172
	M26	0,895	−0,279
RT_{30}	M33	0,920	0,207
	M35	0,910	0,229
C_7	M5	0,990	
	M4	0,987	
C_{50}	M14	0,986	−0,120
	M13	0,983	−0,108
C_{80}	M24	0,975	
	M22	0,973	
C_{35}	M31	0,972	−0,119
	M33	0,968	−0,155
D	M4	0,993	
	M5	0,991	−0,110
$IACC_{Early}$	M7	0,998	
	M9	0,996	
$IACC_{Late}$	M13	0,996	
	M14	0,994	
$IACC_{Full}$	M25	0,998	
	M27	0,996	

Principal component analysis of the reverberation time values for control room R12 shows that the greatest impact on the first two principal components PC1 and PC2 for the parameter EDT have measurements M9 and M7; for the parameter RT_{10} have measurements M12 and M15; for the parameter RT_{20} have measurements M27 and M24, while for the parameter RT_{30} measurements M28 and M36.

3.6 Small control room of "Studio Bajsić" R12

Calculation of the principal components PC1 and PC2 for measuring parameters of reverberation time shows that measurements with all sound sources are present, i.e. omnidirectional sound source as well as monitor loudspeakers.

Principal component analysis of the Clarity C values in the control room R12 indicates that the greatest impact on the first two principal components PC1 and PC2 for parameter C_7 have measurements M8 and M9; for the parameter C_{50} have measurements M18 and M17; for the parameter C_{80} have measurements M22 and M23, while for the parameter C_{35} have measurements M29 and M31.

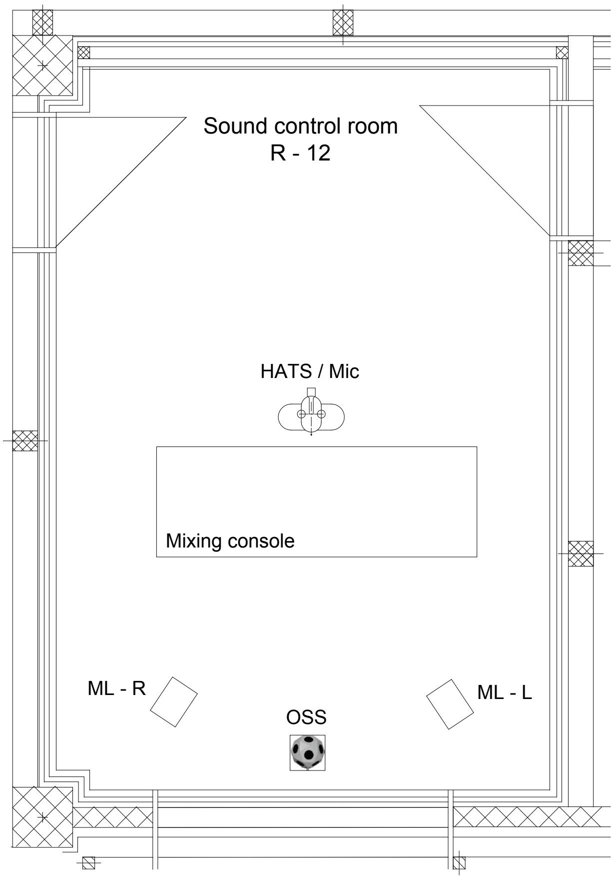

Figure 7 Layout of the small control room of "Studio Bajsić" R12

Table 12 Construction parameters of the small control room of "Studio Bajsić" R12

Width / m	Depth / m	Height / m	Floor area / m^2	Volume / m^3
4,95	7,20	3,40	35,64	121,18

In most cases significant impact in the calculation of the principal components related to the clarity parameter C of control room R12 have measurements performed with control monitor.

Principal component analysis of the Definition D values indicates that the greatest impact on the first two principal components PC1 and PC2 have measurements M8 and M9.

Table 13 Coefficients of principal components of the of objective room quality parameters for the small control room of "Studio Bajsić" R12

Parameter	Measurement	Principal component	
		PC1	PC2
EDT	M9	0,989	−0,121
	M7	0,979	
RT_{10}	M12	0,856	0,407
	M15	0,826	
RT_{20}	M27	0,908	0,265
	M24	0,902	−0,148
RT_{30}	M28	0,929	0,198
	M36	0,921	0,227
C_7	M8	0,997	
	M9	0,997	
C_{50}	M18	0,982	−0,151
	M17	0,979	−0,157
C_{80}	M22	0,982	−0,179
	M23	0,980	−0,191
C_{35}	M29	0,968	0,149
	M31	0,965	−0,200
D	M8	0,989	−0,114
	M9	0,989	−0,100
$IACC_{Early}$	M8	0,992	
	M9	0,992	
$IACC_{Late}$	M11	0,978	−0,202
	M14	0,978	0,163
$IACC_{Full}$	M26	0,993	
	M27	0,992	

Principal component analysis of the interaural cross-correlation coefficient IACC values shows that the first two principal components PC1 and PC2 are mainly defined for parameter $IACC_{Early}$ by measurements M8 and M9; for parameter measurements $IACC_{Late}$ by M11 and M14, and the overall coefficient $IACC_{Full}$ by M26 and M27.

Clearly, measurements taken with control monitor have in most cases a significant impact on the calculation of the first two principal components for IACC coefficient. The measurement taken with omnidirectional sound source is significant in only one case.

4 The final result - standardized measurement setup matrix

After detailed analysis of the measurement results of objective parameters of professional sound control room acoustical quality, as the final result a standardized matrix of measurement setup is produced. The setup matrix shows which sound source and sound source signal has to be used for the measurements that give the best results. The sound source can be either omnidirectional or built-in monitor loudspeaker, used as operational sound control monitor. The exciting signal can be the sweep signal or MLS signal.

From the standardized measurement setup matrix for professional sound control rooms should be noted that the measurement with omnidirectional sound source makes sense when measuring parameters are related to the reverberation time. The energy parameters of clarity C and definition D should be measured with operational control monitor loudspeakers which are used in the control room.

Table 14 Standardized measurement setup matrix

	The label of specified sound control room					
	R1	R4	R5	R13	R11	R12
EDT	OSS-MLS	ML_L-SW_{Log}	OSS -SW_{Lin}	ML_L-SW_{Lin}	ML_L-SW_{Log}	ML_L-MLS
RT_{10}	OSS-SW_{Log}	ML_L-MLS	OSS-SW_{Log}	OSS-SW_{Log}	ML_L-MLS	OSS-MLS
RT_{20}	OSS-MLS	OSS-MLS	ML_L-SW_{Log}	ML_R-MLS	OSS-MLS	ML_L-MLS
RT_{30}	ML_L-MLS	ML_R-SW_{Lin}	ML_L-SW_{Log}	ML_R-SW_{Lin}	ML_R-MLS	OSS-SW_{Lin}
C_7	ML_R-SW_{Log}	ML_L-MLS	ML_R-SW_{Log}	ML_L-SW_{Lin}	ML_R-SW_{Log}	ML_L-SW_{Log}
C_{50}	ML_R-SW_{Lin}	ML_R-MLS	ML_R-MLS	ML_R-SW_{Log}	ML_R-SW_{Log}	ML_L-MLS
C_{80}	ML_L-SW_{Lin}	ML_R-MLS	ML_R-SW_{Log}	ML_L-SW_{Lin}	ML_R-MLS	ML_R-SW_{Lin}
C_{35}	ML_R-SW_{Lin}	ML_L-SW_{Lin}	ML_R-MLS	OSS-SW_{Lin}	ML_R-SW_{Lin}	OSS-SW_{Log}
D	ML_R-SW_{Lin}	ML_R-SW_{Lin}	ML_R-MLS	ML_R-SW_{Lin}	ML_R-SW_{Lin}	ML_L-SW_{Log}
$IACC_{Early}$	OSS-MLS	ML_L-SW_{Log}	ML_R-SW_{Log}	ML_L-SW_{Log}	ML_L-SW_{Lin}	ML_L-SW_{Log}
$IACC_{Late}$	ML_R-SW_{Log}	ML_R-SW_{Log}	OSS-SW_{Lin}	ML_R-SW_{Log}	ML_R-SW_{Lin}	OSS-SW_{Log}
$IACC_{Full}$	OSS-MLS	ML_L-SW_{Log}	ML_R-SW_{Log}	ML_L-SW_{Log}	ML_L-SW_{Lin}	ML_L-SW_{Log}

Legend:
OSS – Omnidirectional Sound Source (Shaded cells); ML – Monitor Loudspeaker (L – Left, R – Right);
MLS – Maximum Length Sequence Signal; $SW_{Log//Lin}$ – Sweep signal with Logarithmic/Linear sweep

5 Conclusion

Sound control rooms are special rooms where acoustic quality is of special importance and it is crucial to exactly define room layout and achieve the best acoustic quality parameters. Analysis of such requirements shall facilitate in achieving such quality. This paper presents a mathematical analysis of the measurement results using Principal Component Analysis. Results of measurement of objective room acoustic quality parameters are exactly specified by the conditions under which they are measured and will be put in correlation with subjective assessment of sound control room further research. Therefore, it is extremely important to exactly determine the measurement's conditions and setup that will give the most accurate measurement results. Final results show the measurement setup for each observed parameter, separately for each sound control room. Thus, the results are obtained, which determine the value of subjective assessments of the room in the best possible way. The presented results also provide a basis for future statistical analysis and correlations between the size and shape of the room and type of sound source and/or signal with particular parameter of acoustic quality of the sound control room. This method also allows the optimization of the acoustic characteristics of the sound control rooms with adequate acoustic quality.

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