Speech Intelligibility in Serbian Orthodox Churches and IEC 60268 – 16 Standard

Violeta Stojanović[1], Zoran Milivojević[2] and Momir Praščević[3]

Abstract – **This paper presents an analysis of the speech intelligibility in Serbian Orthodox churches "St. George" in Žitni Potok and "St. Prokopije" in Katun, which was based on the measured values of the objective acoustic STI parameter and IEC 60268-16 Standard. The first part of the paper includes tables and graphs presenting results of the calculated values of STI parameter (obtained on the basis of practical measurements of acoustic impulse responses in the churches) and the corresponding percentages values of the intelligibility of sentences, PB words and CVC logatoms set by the Standard. The second part of the paper includes correlation and regression analyses of the results, as well as the conclusion.**

Keywords – **Objective acoustic parameter STI, IEC 60268-16 Standard, Correlation and regression.**

I. INTRODUCTION

Speech is the main means of communication among people. In many situations, the voice signal degrades while transmitting the channel between the speaker and the listener. This results in a decreased speech intelligibility at the location of the listener.

One of the methods of assessing the intelligibility of the listener's speech is the method of measuring the objective Speech Transmission Index *STI*. This method has been the subject of continuous development and refinement since it was introduced in the 1970s, as confirmed by many revisions of IEC 60268-16 Standard [1]. Houtgast and Steeneken described in 1973. an objective method for estimating the speech intelligibility in rooms by calculating a physical index from the modulation transfer function (*MTF*) [2]. This physical index, called the Speech Transmission Index (*STI*) is calculated at discrete frequencies, weighted, summed and normalized to yield a single index of speech intelligibility. Houtgast and Steeneken modified the original *STI* model in 2002. [3]. They established a relationship between the revised Speech Transfer Index (*STI_r*) and subjective speech intelligibility. The revised Speech Transmission Index (*STI_r*) is obtained by a weighted summation of the modulation transfer indices for all octave bands and the corresponding corrections of excessive repetition. The redundancy correction is related to the contribution of adjacent frequency bands [3].

The relationship between the objective acoustic parameter *STI* and the speech intelligibility (expressed as percentage) is shown in Table I [1]. This correlation was made using intelligibility of [2]: a) syllables, b) words from the so-called "Harvard List" and c) sentences, using the Speech Reception Threshold (SRT) method. Fig. 1. shows the relationship between the revised Speech Transmission Index (*STI_r*) and subjective intelligibility: a) sentences, b) PB words, and c) CVC logatoms [1].

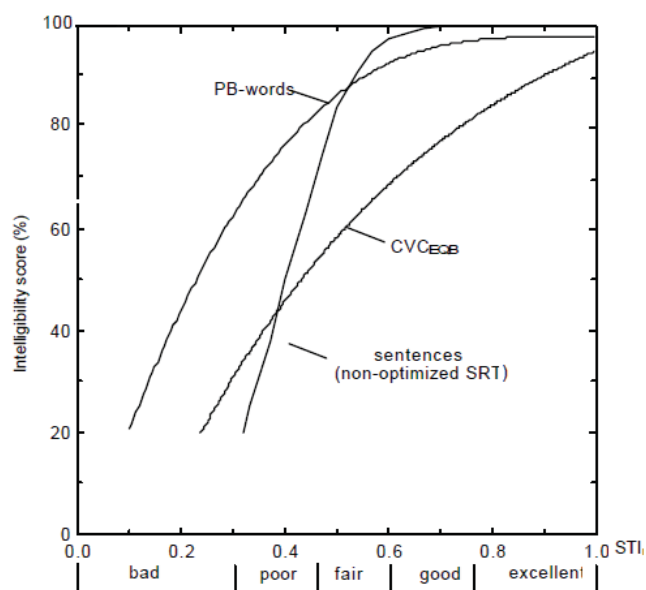| STI	Quality according to: IEC 60268-16	SI_s (%)	SI_w (%)	SI_{sent} (%)
0 ÷ 0.3	bad	0 ÷ 34	0 ÷ 67	0 ÷ 89
0.3 ÷ 0.45	poor	34 ÷ 48	67 ÷ 78	89 ÷ 92
0.45 ÷ 0.6	fair	48 ÷ 67	78 ÷ 87	92 ÷ 95
0.6 ÷ 0.75	good	67 ÷ 90	87 ÷ 94	95 ÷ 96
0.75 ÷ 1	excellent	90 ÷ 96	94 ÷ 96	96 ÷ 100

Fig. 1. Classification of the relationship of speech intelligibility and *STI*.

In this paper, we analyzed the speech intelligibility for two Serbian Orthodox churches and this was based on measured values of objective acoustic parameters *STI* at central frequencies f_c = {500 Hz, 2 kHz} and the quality of speech intelligibility according to IEC 60268-16 Standard. The values of objective acoustic parameters *STI* were determined

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according to the measurement of acoustic impulse response and EASERA software package. The classification of speech intelligibility in acoustically examined churches was determined by the relationship between the value of *STI* parameters and the percentage of speech intelligibility of sentences SI_{sent}, PB words SI_{PBw} and CVC logatoms SI_{CVC}, set by the Standard. The relationship between these quantities was determined by correlation and regression analyses, using Matlab software package.

The paper is organized as follows: Section II explains the experiment and presents the experimental results; Section III shows the analysis of the results and Section IV is the conclusion.

II. EXPERIMENT

The process of measuring impulse response was carried out in two Serbian Orthodox churches: 1) the church "St. George" in Žitni potok and 2) the church "St Prokopije" in Katun. Analysis of acoustic objective parameters in these churches is explained in detail in [4].

The church "St. George" in Žitni Potok (church 1) has a volume of $V = 2163$ m^3 and inner area is $S = 167$ m^2. The church "St Prokopije" in Katun (church 2) has a volume of V $= 1659.68$ m^3 and inner area is S $= 646.68$ m^2. The interior walls and the ceilings in the churches covered with plaster (the coefficient of absorption $\alpha = 0.02$). The floors with the ceramic tiles (the coefficient of absorption $\alpha = 0.015$).

For the purpose of the analysis in this paper, we took the acoustic impulse responses measured at MP = 9 measuring points in both churches. Their arrangement is shown in Fig. 2. and Fig. 3. The database includes 63 wav files that were obtained by recording the acoustic impulse response using the software package EASERA. For each measuring point, 7 measurements were made. Sound source LS is placed near the altar.

The equippment used for the experiment as follows: (a) an omnidirectional microphone (PCB 130D20), having a diaphragm diameter of 7mm; (b) a B&K omnidirectional sound source type 4295 (dodecahedron loudspeaker); (c) a B&K audio power amplifier, rated at 100W RMS, stereo, type 2716-C; (d) a laptop, incorporating a Soundmax Integrated Digital Audio sound card from Analog Devices. Measuring of the impulse response is carried out using incentive log sweep signal with the duration of 5 s sampling frequency is fS = 44.1 kHz. The procedure for recording and calculation of acoustic parameters was performed in accordance with ISO 3382.

The mean values of *STI* parameters at all measured MP positions in the churches, at $f_c = \{500$ Hz, 2 kHz$\}$, were calculated using the EASERA software package. Based on the classification of the speech intelligibility and the *STI* parameter set by the Standard (Fig. 1.), the values of the speech intelligibility were determined as follows: sentences SI_{sent}, PB words SI_{PBw} and CVC logatoms SI_{CVC} for each MP position in the churches. Next, mean values $\overline{SI_{sent}}$, $\overline{SI_{PBw}}$ and $\overline{SI_{CVC}}$ were calculated for all measured MP positions in
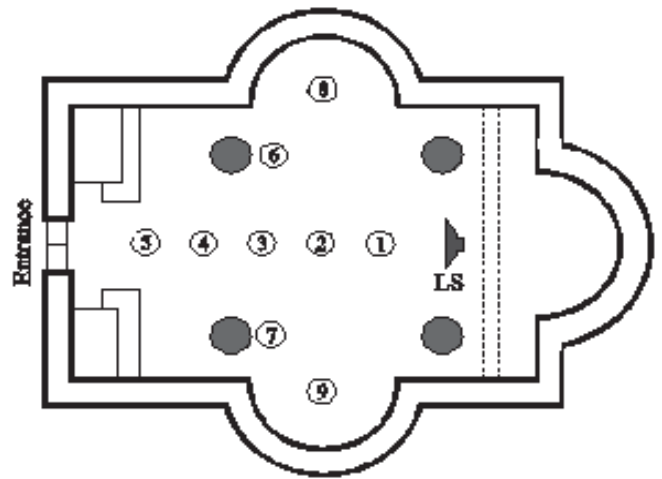

Fig. 2. The position of the measuring points MP and sound source LS in the church "St. George" in Zitni Potok.
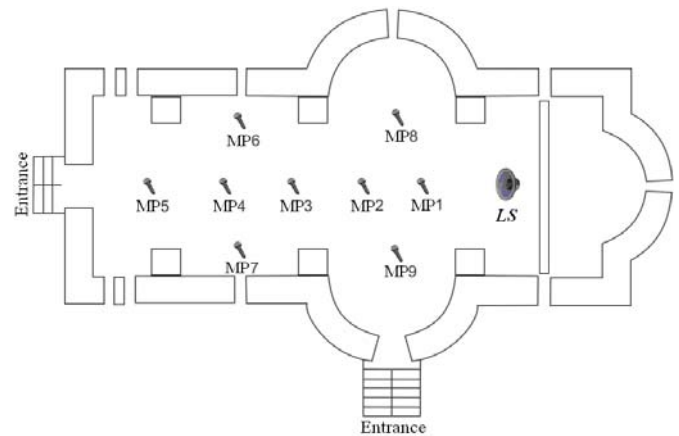

Fig. 3. The position of the measuring points MP and sound source LS in the church "St Prokopije" in Katun.

church 1 and church 2. The assessment of the quality of speech in the churches was performed according to the Standard (Table I). The strength of the relationship between the objective *STI* parameter and the qualifying values of speech intelligibility qualities: SI_{sent}, SI_{PBw} and SI_{CVC} for both churches individually, at $f_c = \{500$ Hz, 2 kHz$\}$, was determined by regression and correlation analyses.

A. Resultats of the experiment

Tables II and III show the values of objective *STI* parameters and the values of subjective speech intelligibility SI_{sent}, SI_{PBw} and SI_{CVC} at the central frequencies $f_c = \{500$ Hz, 2 kHz$\}$ for church 1 and church 2, respectively. Table IV shows the mean values of these measures for both churches. Figs. 4. -6. show regression lines for measures *STI* and SI_{sent}, *STI* and SI_{PBw} and *STI* and SI_{CVC} at central frequencies $f_c = \{500$ Hz, 2 kHz$\}$ for church 1. Figs. 7. – 9. show lines regression of these measures, at the same frequencies, for church 2.

TABLE II
THE VALUES *STI*, *SI~SENT~*, *SI~PBW~* AND *SI~CVC~* AT 500 Hz AMD 2kHz FOR THE CHURCH 1

	f = 500 Hz								
	MP								
	1	2	3	4	5	6	7	8	9
STI	0.66	0.53	0.51	0.4	0.38	0.37	0.34	0.37	0.45
SI~sent~ (%)	99	90	62	50	40	36.5	27	36.5	67
SI~PBw~ (%)	95.2	89	81	76	73	72.5	68	72.5	82
SI~CVC~ (%)	74.5	62	52.5	46	43	41	37	41	52.5
	f = 2kHz								
STI	0.77	0.62	0.5	0.46	0.4	0.37	0.35	0.39	0.58
SI~sent~ (%)	100	98	84	70	50	36.5	31	44	96
SI~PBw~ (%)	97	93.5	87	82	76	72.5	70	74.5	92
SI~CVC~ (%)	82	70.1	58	54	46	41	38.5	43	68.5

TABLE III
THE VALUES *STI*, *SI~SENT~*, *SI~PBW~* AND *SI~CVC~* AT 500 Hz AND 2kHz FOR THE CHURCH 2

	f = 500 Hz								
	MP								
	1	2	3	4	5	6	7	8	9
STI	0.57	0.49	0.44	0.38	0.37	0.42	0.43	0.44	0.48
SI~sent~ (%)	95	81	64	40	36.5	57	61	64	77
SI~PBw~ (%)	91	85.05	81	73	72.5	78.5	80	81	84
SI~CVC~ (%)	66.5	58	51.5	43	41	48.5	50	51.5	56.5
	f = 2kHz								
STI	0.69	0.55	0.54	0.52	0.5	0.57	0.57	0.58	0.56
SI~sent~ (%)	100	97	96	87.5	90	95	95	96	94
SI~PBw~ (%)	96	90	89.5	87.5	89	91	91	92	90.1
SI~CVC~ (%)	74.5	64	62.5	61	62	66	66	67	65

TABLE IV
THE MEAN VALUES $\overline{STI}$, $\overline{SI_{sent}}$, $\overline{SI_{PBw}}$ AND $\overline{SI_{CVC}}$ AT 500 Hz AND 2kHz FOR BOTH CHURCHES

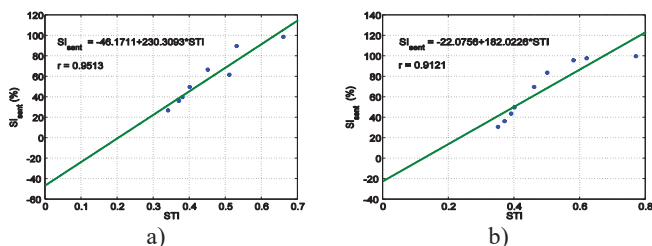|	Church 1		Church 2	
f (Hz)	500	2000	500	2000
$\overline{STI}$	0.44 poor	0.45 poor-fair	0.45 poor-fair	0.57 fair
$\overline{SI_{sent}}$ (%)	64 bad	70 bad	66.5 bad	95 fair-good
$\overline{SI_{PBw}}$ (%)	81 fair	82 fair	81.5 fair	91 good
$\overline{SI_{CVC}}$ (%)	51.5 fair	54 fair	52.5 fair	66 fair

Fig. 4. The regression line for *SI~sent~* and *STI* at: a) 500 Hz and b) 2kHz for the Church 1.
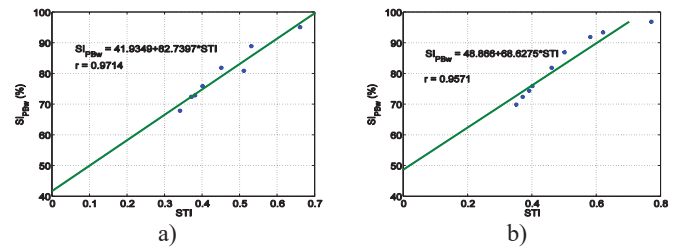

Fig. 5. The regression line for *SI~PBw~* and *STI* at: a) 500 Hz and b) 2kHz for the Church 1.
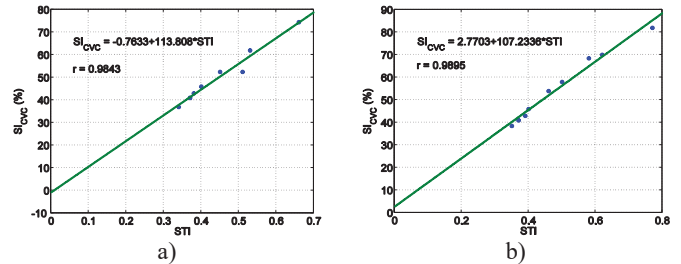

Fig. 6. The regression line for *SI~CVC~* and *STI* at: a) 500 Hz and b) 2kHz for the Church 1.
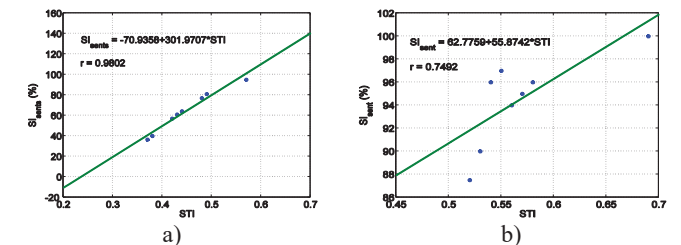

Fig. 7. The regression line for *SI~sent~* and *STI* at: a) 500 Hz and b) 2kHz for the Church 2.
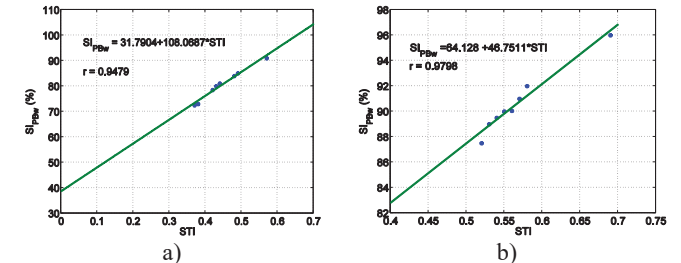

Fig. 8. The regression line for *SI~PBw~* and *STI* at: a) 500 Hz and b) 2kHz for the church 2.
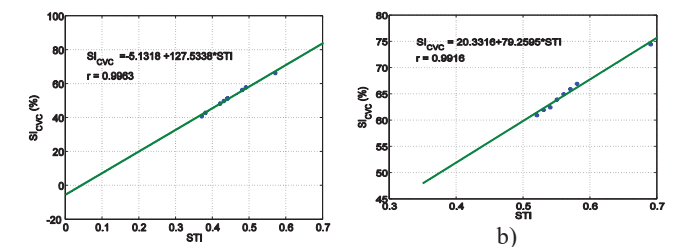

Fig. 9. The regression line for *SI~CVC~* and *STI* at: a) 500 Hz and b) 2kHz for the church 2.

B. The results analysis

Based on the results shown in the Tables II - IV and the Figs 4. – 9. the following can be concluded:

1) for church 1: a) At f = 500 Hz mean value of the objective parameter $\overline{STI}$ = 0.44 classifies poor intelligibility of speech. According to the criteria for the subjective intelligibility of speech set by the Standard, the mean $\overline{SI_{sent}}$ = 64% determines poor intelligibility of sentences while the values $\overline{SI_{PBw}}$ = 81% and $\overline{SI_{CVC}}$ = 51.5% determine fair intelligibility of PB words and CVC logatoms. b) At f = 2 kHz is $\overline{STI}$ = 0.45 and determines the intelligibility of speech that is at the border line between poor and fair. The intelligibility of sentences is poor, and the intelligibility of PB words and CVC logatoms is fair ($\overline{SI_{sent}}$ = 70%, $\overline{SI_{PBw}}$ = 82% i $\overline{SI_{CVC}}$ = 54%).

2) for church 2: a) At f = 500 Hz speech comprehension is at the border line between poor and faire because the mean value of the objective parameter is $\overline{STI}$ = 0.45. And here the poor intelligibility have sentences, $\overline{SI_{sent}}$ = 64% and faire intelligibility of PB words and CVC logatoms, $\overline{SI_{PBw}}$ = 81.5% and $\overline{SI_{CVC}}$ = 52.5%. b) Compared to previous results concerning the speech intelligibility, church 2 at 2 kHz shows the best rating of speech intelligibility- faire ($\overline{STI}$ = 0.57). The intelligibility of sentences is at the border line between faire - good, $\overline{SI_{sent}}$ = 95%, because $\overline{SI_{sent}}$ = 64% The intelligibility of PB words is good ($\overline{SI_{PBw}}$ = 91.%), whereas the intelligibility of CVC logatoms is acceptable ($\overline{SI_{CVC}}$ = 66%).

3) for church 1, the correlation and regression analysis gave the following connection of the investigated quantities with the corresponding Pearson coefficients at a) f = 500 Hz and b) f = 2 kHz:
a) SI_{sent} = -46.1711 + 230.3093 STI, r = 0.9513;
$SI_{ŠBw}$ = 41.9349 + 82.7397 STI, r = 0.9714;
SI_{CVC} = -0.7633 + 113.808 STI, r = 0.9843;
b) SI_{sent} = -22.0756 + 182.0226 STI;
$SI_{ŠBw}$ = 48.666 + 68.6275 STI, r = 0.9571;
SI_{CVC} = 2.7703 + 107.2336 STI, r = 0.9895.
This analysis shows that there is a statistically positive, strong, linear connection between the objective parameter STI and the subjective intelligibility of speech SI_{sent}, SI_{PBw} i SI_{CVC}

4) for church 2, the correlation and regression analysis gave the following connection of the investigated quantities with the corresponding Pearson coefficients at a) f = 500 Hz and b) f = 2 kHz:
a) SI_{sent} = -70.9358 + 301.9707 STI, r = 0.9802;
$SI_{ŠBw}$ = 31.7904 + 108.0687 STI, r = 0.9479;
SI_{CVC} = -5.1318 + 127.5338 STI, r = 0.9963;
b) SI_{sent} = 62.7759 + 55.8742 STI;
$SI_{ŠBw}$ = 64.128+ 46.7511 STI, r = 0.9798;
SI_{CVC} = 20.3316 + 79.2595 STI, r = 0.9916.

There is also a statistically positive, strong, linear connection between the objective STI parameter and the subjective speech intelligibility SI_{sent}, $SI_{ŠBw}$ and SI_{CVC}.

III. CONCLUSION

In this paper, for two Serbian Orthodox churches: 1) the church "Sveti Đorđe" in Žitni potok and 2) the church "Sveti Prokopije" in Katun, we analyzed the intelligibility of speech sentences SI_{sent}, PB words SI_{PBw} and CVC logatoms SI_{CVC}, based on the calculated values of STI acoustic parameters for central frequencies f_c = {500 Hz, 2 kHz}, and the quality of comprehensibility of speech according to the Standard IEC 60268 - 16.The relationship between these acoustic parameters was analyzed using regression and correlation parameters.

The mean values of the objective acoustic STI parameter for both churches classify poor and fair of speech intelligibility: $\overline{STI}$ = {0.44, 0.45} i $\overline{STI}$ = {0.45, 0.57} for churches 1 and 2, respectively. Such quality of speech intelligibility results in: 1) poor intelligibility of sentences in church 1: $\overline{SI_{sent}}$ = {64%, 70%} and in church 2 at f_c = 500 Hz, $\overline{SI_{sent}}$ = 66.5%, whereas the intelligibility is faire - good in church 2 at f_c = 2 kHz, $\overline{SI_{sent}}$ = 95%; 2) faire intelligibility of PB words in church 1: $\overline{SI_{PBw}}$ = {81.5%, 82%} as well as in church 2 at f_c = 500 Hz, $\overline{SI_{PBw}}$ = 81.5%, and good intelligibility in church 2 at f_c = 2 kHz, $\overline{SI_{PBw}}$ = 91% and 3) faire intelligibility of CVC logatoms in both churches: $\overline{SI_{CVC}}$ = {51.5%, 54%} and $\overline{SI_{CVC}}$ = {52.5%, 66%}.The correlation and regression analyses confirmed a statistically positive, strong, linear connection (r ≥ 0.7) between the acoustic objective Speech Transmission Index STI and the subjective intelligibility of speech analyzed according to the comprehensibility of sentences, PB words and CVC logatoms set by the Standard.

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