THE EVALUATION QUALITY OF THE SPEECH INTELLIGIBILITY IN THE ORTHODOX CHURCH "HOLI GREAT MARTYR PROCOPIUS" IN KATUN

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Abstract

This paper presents the evaluation of the quality of the objective and subjective intelligibility of speech for the unoccupied and occupied Serbian Orthodox Church "Holy Great Martyr Prokopija" in Katun. The first part of the paper includes a description of the Experiment, tabularly and graphically presented results of the calculated values, that is the reverberation time, RT_{30}, the objective index of speech transmission STI, the corresponding values of the subjective speech intelligibility for the unoccupied church, estimated values of the analyzed acoustic parameters for the occupied church, and the speech intelligibility quality of the analyzed unoccupied and occupied church determined according to Standard IEC 60268 - 16. The second part of the paper includes correlation and regression analyses of the results as well as the conclusion.

Keywords: Reverberation, speech transmission index *STI*, intelligibility, correlation, regression, Standard IEC 60268 - 16.

1. INTRODUCTION

From the aspect of acoustic treatment in ortodox churches, there are three distinctive forms of audio information as part of sound components: a) chanting of a priest, b) polichronic chanting of a priest and a choir, and c) the sermons [1]. Acoustic design of a church must meet the requirements of all three sound forms, i.e. the most important parameter which is the reverberation time, *RT*.

Wallace Sabine introduced reverberation time, in 1922 as a measure of acoustic conditions in rooms [2]. Since then, this acoustic parameter has an irreplaceable role for the subjective experience of loudness, but it has an aesthetic function primarily, because it is one of the basic elements of responsiveness from the aspect of influence on the overall subjective experience of sound.

Speech intelligibility, *SI*, in churches can be increased by reducing the reverberation time due to the increase in sound absorption caused, among other things, by the presence of believers in the church premises [2]. Reverberation time, as well as other room acoustic parameters, can be obtained from the room impulse response, RIR [3].

The software package for Audio Real Time Analysis, ARTA, among other packages, is developed for the purpose of recording the impulse response of the room. ARTA from 2010., is the program for measuring impulse responses and analyzing the spectrum and the frequency response in real time [4].

In this paper, an evaluation of the quality of objective and subjective intelligibility of speech was performed for the unoccupied and occupied Serbian Orthodox Church "Holy Great Martyr Prokopija" in Katun. The values of the objective acoustic parameters, the reverberation time RT_{30} and the speech transmission index, *STI*, on the basis of the measurement of acoustic impulse responses and the ARTA software package, were determined [5]. First a connection was established between the measured values of RT_{30} at the central frequency $f_c = 2$ kHz and the objective acoustic parameters of the *STI*. Next, using the Standard IEC 60268 - 16 the percentage values and the quality of the subjective speech intelligibility of sentences SI_{sent}, PB words, SI_{PBw} and CVC (*C* - Consonant, *V* - Vocal) logatoms SI_{CVC}, were

determined [6]. Using the Matlab software package, the connection between subjective speech intelligibility and reverberation time was determined by correlation and regression analysis.

The paper is organized as follows. Section II explains the Experiment. Section III presents the experimental results and analysis. Section IV is the Conclusion.

2. THE EXPERIMENT

The experiment was carried out in Serbian Orthodox Church "Holy Great Martyr Prokopija" in Katun, East Serbian. Volume of the church is $V = 1659.68$ m^3 and its area $S = 646.68$ m^2. The interior walls and ceilings are covered with plaster (the coefficient of absorption $\alpha = 0.02$). The floor is with the ceramic tiles (the coefficient of absorption $\alpha = 0.015$).

The method used to calculate the $RT_{30unocc}$ and STI_{unocc} of the unoccupied church is based on the measurement of RIR and the use of the ARTA software package. The recording procedure, as well as the evaluation of the parameters, were performed in accordance with the ISO 3382 [7].

The equipment used for the experiment is as follows: a) an omnidirectional microphone (PCB 130D20), with a diaphragm diameter of 7 mm; 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 $f_S = 44.1$ kHz. For the purpose of analysis in this paper, $RIRs$ are measured in $MP = 9$ measuring points of the church were taken, the layout of which is shown in fig. 1. For each MP, 7 measurements were made, which makes a total of 63 files.

Based on classification of the ratio of speech intelligibility and the STI parameter established by the IEC 60268-16 – International Standard [6], the speech intelligibility were determined: $SI_{sent-unocc}$, $SI_{PBw-unocc}$ and SI_{CVC} for each MP in the unoccupied church.
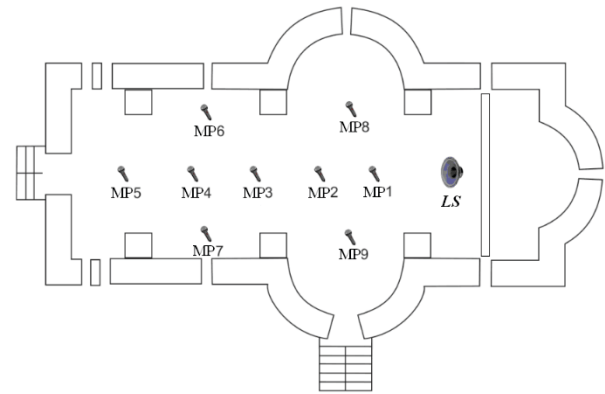

Fig. 1. *The church where the impulse response is measured: LS the location of the sound source, MP 1-9 - measured points.*

Then, the mean and standard deviations of these quantities for all MP in the unoccupied church, were calculated. For the occupied church, for each MP measurement position, the following is calculated:

a) predicted reverberation time RT_{30occ} using [8]:

$$RT_{occ} = RT_{unocc} - DT , \qquad (1)$$

where DT is Schultz diffusion time, and

b) estimation of speech transmission index parameter STI_{occ} by [9]:

$$STI_{occ} = STI_{unocc} + \Delta STI . \qquad (2)$$

ΔSTI is a value calculated using the following formula:

$$\Delta STI = 0.45 \, ln \frac{RT_{unocc}(2kHz)}{RT_{occ}(2kHz)} + 0.012 . \qquad (3)$$

Using the IEC 60268-16 – International Standard [6], speech intelligibility: a) $SI_{sent-unocc}$, b) $SI_{PBw-unocc}$ and c) SI_{CVC}, for each MP measurement position in the occupied church, were determined. Then, the mean and standard deviations of these quantities for all MP measurement positions in the occupied church, were calculated. The assessment of the quality of speech in the church was based on IEC 60268-16 Standard [6]. The intensity of the connection between the objective parameters RT_{30} and STI and the acoustic parameters, that qualify the subjective speech intelligibility: SI_{sent}, SI_{PBw} and SI_{CVC} for the unoccupied and

occupied church, at 2 kHz, was determined by regression and correlation analysis.

3. RESULTS OF THE EXPERIMENT AND ANALYSIS

3.1 THE RESULTS

Table 1 shows the numerical values of the following acoustic quantities at the central frequency $f = 2$kHz: a) $RT_{30unocc}$, STI_{unocc}, $SI_{sent-unocc}$, $SI_{PBw-unocc}$ and $SI_{CVC-unocc}$ for each MP measurement position as well as the mean and standard deviations of these quantities for all MP measurement positions in the unoccupied church and b) RT_{30occ}, STI_{occ}, $SI_{sent-occ}$, $SI_{PBw-occ}$ and $SI_{CVC-occ}$ for each measurement position, MP, as well as the mean and standard deviations of these quantities for all MP in the occupied church. Table 1 also shows the quality rating of speech intelligibility that corresponds to certain values of objective and subjective acoustic parameters.

Fig. 2 - fig. 5 show regression lines for measures: STI_{unocc} and $RT_{30unocc}$, $SI_{sent-unocc}$ and $RT_{30unocc}$, $SI_{PBw-unocc}$ and $RT_{30unocc}$ and $SI_{CVC-unocc}$ and $RT_{30unocc}$ at central frequency $f_c = 2$ kHz for unoccupied church. Figs. 6 -9 show regression lines for measures: STI_{occ} and RT_{30occ}, $SI_{sent-occ}$ and RT_{30occ}, $SI_{PBw-occ}$ and RT_{30occ} and $SI_{CVC-occ}$ and RT_{30occ} at central frequency $f_c = 2$ kHz for occupied church.

3.2. ANALYSIS OF THE RESULTS

Based on the results shown in Table 1 and Figs 2 – 9 and IEC 60268-16 Standard, the following can be concluded:

1) for an unoccupied church: a) the mean of the reverberation time $\overline{RT_{30unocc,MP}} = 1.53 \pm 0.1$ s $= 1.43 \div 1.63$ s; b) the mean of the speech transfer index $\overline{STI_{unocc}} = 0.57 \pm 0.05 = 0.52 \div 0.62$ classifies speech intelligibility from fair to good; c) the $\overline{SI_{sent-unocc}} = 92.78 \pm 4.15$ % $= 88.63 \div 96.93$ % classifies the subjective intelligibility of sentences from bad to excellent; d) the $\overline{SI_{PBw-unocc}} = 90.33 \pm 2.34$ % $= 87.99 \div 92.67$ % classifies the subjective intelligibility of PB words as good, and e) the $\overline{SI_{CVC-unocc}} = 64.48 \pm 3.32$ % $= 61.16 \div 67.8$ % classifies the subjective intelligibility of CVC logatom from fair to good.
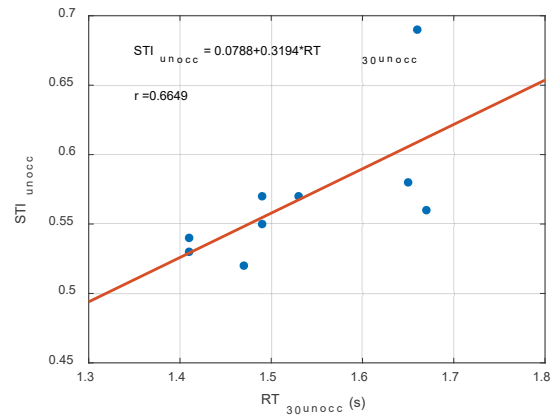

Fig. 2. *The regression line for STI_{unocc} and $RT_{30unocc}$ for the unoccupied church at 2kHz*
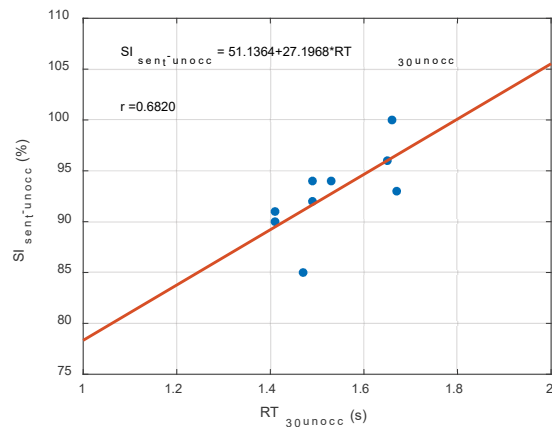

Fig. 3. *The regression line for $SI_{sent-unocc}$ and $RT_{30unocc}$ for the unoccupied church at 2kHz*
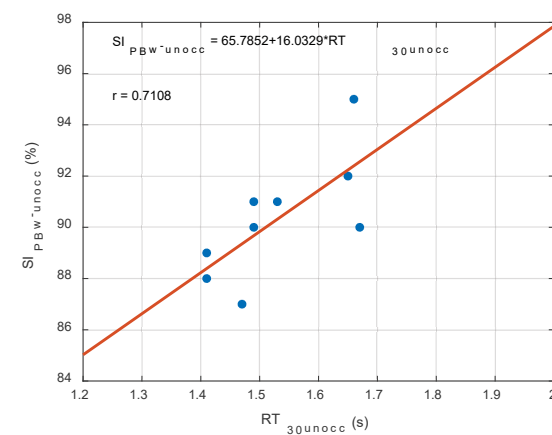

Fig. 4. *The regression line for $SI_{PBw-unocc}$ and $RT_{30unocc}$ at 2kHz for the unoccupied church*

2) for an unoccupied church the correlation and regression analysis gave the following connection of subjective speech intelligibility

Table 1. *Reverberation time RT₃₀, objective speech transmission index STI, subjective speech intelligibility SI (sentence, PB words and CVC logatoms), their mean, standard deviations and speech quality for the unoccupied and the occupied church.*

MP	$RT_{30unocc}$ (2 kHz) (s)	STI_{unocc}	$SI_{sent-unocc}$ (%)	$SI_{PBw-unocc}$ (%)	$SI_{CVC-unocc}$ (%)	RT_{30occ} (2 kHz) (s)	STI_{occ}	$SI_{sent-occ}$ (%)	$SI_{PBw-occ}$ (%)	$SI_{CVC-occ}$ (%)
1	1.66	0.69	100	95	72	1.4	0.78	100	97	84
2	1.49	0.55	92	90	64	1.34	0.61	97	93	70
3	1.41	0.54	91	89	63	1.32	0.58	96	92	66
4	1.47	0.52	85	87	60	1.34	0.57	94	91	65
5	1.41	0.53	90	88	62	1.32	0.57	94	91	65
6	1.53	0.57	94	91	65	1.36	0.64	98	93	73
7	1.49	0.57	94	91	65	1.34	0.63	98	93	71
8	1.65	0.58	96	92	66	1.39	0.67	99	95	75
9	1.67	0.56	93	90	64	1.4	0.65	98	94	73

| $RT_{30unocc,MP}$ (2 kHz) (s)	STI_{unocc}	$SI_{sent-unocc}$ (%)	$SI_{PBw-unocc}$ (%)	$SI_{CVC-unocc}$ (%)	$RT_{30occ,M}$ (2 kHz)(s)	STI_{occ}	$SI_{sent-occ}$ (%)	$SI_{PBw-occ}$ (%)	$SI_{CVC-occ}$ (%)
1.53	0.57	92.78	90.33	64.48	1.36	0.63	97.11	93.22	71.33
σ	σ	σ	σ	σ	σ	σ	σ	σ	σ
$RT_{30unocc,MP}$ (2 kHz) (s)	STI_{unocc}	$SI_{sent-unocc}$ (%)	$SI_{PBw-unocc}$ (%)	$SI_{CVC-unocc}$ (%)	$RT_{30occ,M}$ (2 kHz)(s)	STI_{occ}	$SI_{sent-occ}$ (%)	$SI_{PBw-occ}$ (%)	$SI_{CVC-occ}$ (%)
0.1	0.05	4.15	2.34	3.32	0.03	0.07	2.09	1.92	6.02
Rating									
-	fair good	bad excellent	good	fair good	-	fair good	good excellent	good excellent	fair good
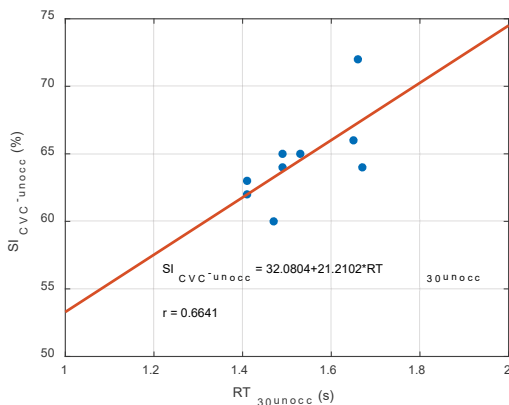
Fig. 5. *The regression line for SI_CVC-unocc and RT_30unocc at 2kHz for the unoccupied church*
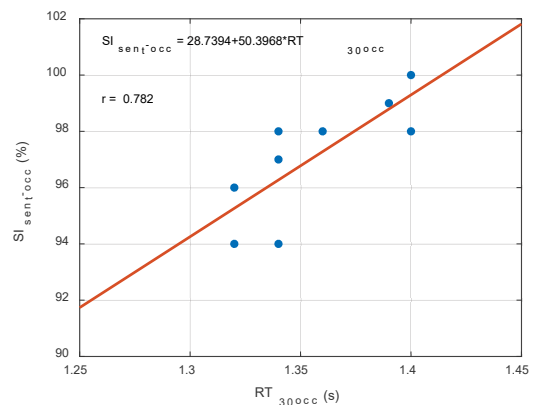

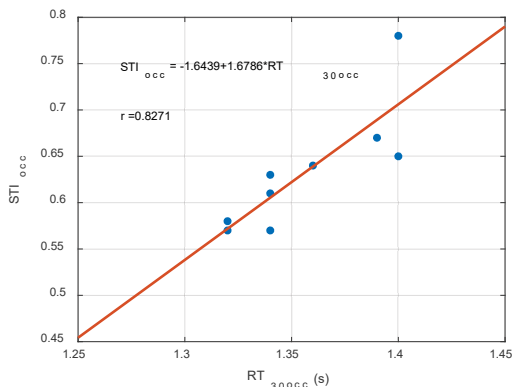**Fig. 7.** *The regression line for SI_sent-occ and RT_30occ at 2kHz for the occupied church*

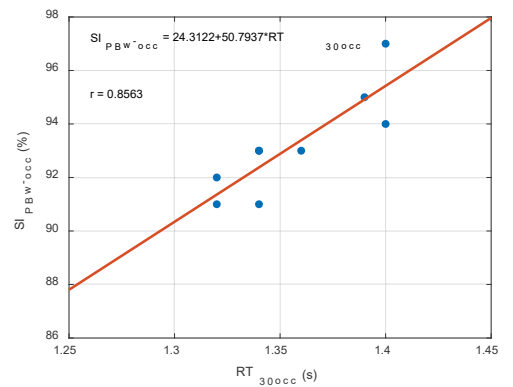**Fig. 6.** *The regression line for STI_occ and RT_30occ for the occupied church at 2kHz*

Fig. 8. *The regression line for SI_PBw-occ and RT_30occ at 2kHz for the occupied church*
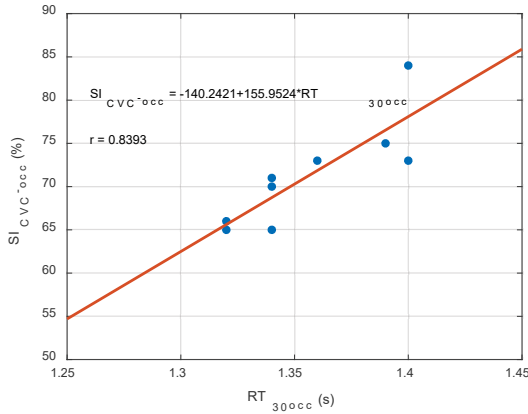
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Fig. 9. *The regression line for SI$_{CVC-occ}$ and RT$_{30occ}$ at 2kHz for the occupied church*

and reverberation time with the corresponding Pearson coefficients at $f = 2$ kHz:

- $STI_{unocc} = 0.0788 + 0.3194\ RT_{30unocc}$,
   $r = 0.6649$;
- $SI_{sent-unocc} = 51.1364 + 27.1968\ RT_{30unocc}$,
   $r = 0.6820$;
- $SI_{PBw-unocc} = 65.7852 + 16.0329\ RT_{30unocc}$,
   $r = 0.7108$ and
- $SI_{CVC-unocc} = 32.0804 + 21.2102\ RT_{30unocc}$,
   $r = 0.6641$.

This analysis shows that for an unoccupied church there is a statistically positive, moderate linear connection between the subjective speech intelligibility: $SI_{sent-unocc}$, $SI_{PBw-unocc}$ and $SI_{CVC-unocc}$ and the reverberation time $RT_{30unocc}$.

3) for an occupied church: a) the mean of the reverberation time is $\overline{RT_{30occ,MP}} = 1.36 \pm 0.03$ s $= 1.33 \div 1.39$ s; b) the mean of the speech transfer index $\overline{STI_{occ}} = 0.63 \pm 0.07 = 0.56 \div 0.7$ classifies speech intelligibility from fair to good; c) the mean $\overline{SI_{sent-occ}} = 97.11 \pm 2.09\ \%$ $= 95.02 \div 99.2\ \%$ classifies the subjective intelligibility of sentences from good to excellent; d) the mean $\overline{SI_{PBw-occ}} = 93.22 \pm 1.92$ % $= 91.3 \div 95.14\ \%$ classifies the subjective intelligibility of PB words from good to excellent and e) the mean value $\overline{SI_{CVC-occ}} = 71.33 \pm 6.02\ \% = 65.31 \div 77.35\ \%$ classifies the subjective intelligibility of CVC logatom from fair to good.

4) for an occupied church the correlation and regression analysis gave the following connection of subjective speech intelligibility and reverberation time with the corresponding Pearson coefficients at $f = 2$ kHz:
- $STI_{occ} = -1.6439 + 1.6786\ RT_{30occ}$, $r = 0.8271$;

- $SI_{sent-occ} = 28.7394 + 50.3968\ RT_{30occ}$,
   $r = 0.782$;
- $SI_{PBw-occ} = 24.3122 + 50.7937\ RT_{30occ}$,
   $r = 0.8563$ and
- $SI_{CVC-occ} = -140.2421 + 155.9524\ RT_{30occ}$,
   $r = 0.8393$.

This analysis shows that for an occupied church there is a statistically positive, strong linear connection between the subjective speech intelligibility: $SI_{sent-occ}$, $SI_{PBw-occ}$ and $SI_{CVC-occ}$ and the reverberation time RT_{30occ}.

CONCLUSION

In this paper, for the unoccupied and occupied Serbian Orthodox Church "Holy Great Martyr Prokopija" in Katun, the evaluation of the quality speech intelligibility is presented using estimation, comparison, as well as correlation, and regression analysis.

The mean of the reverberation time for the unoccupied church belongs to the range $\overline{RT_{30unocc,MP}} = 1.43 \div 1.63$ s. As believers enter the church, due to increased sound absorption, the values of this acoustic parameter decrease. Namely, for the occupied church, the mean of the reverberation time belongs to the range $\overline{RT_{30occ,MP}} = 1.33 \div 1.39$ s. Due to the reduction of reverberation time, the objective and subjective intelligibility of speech increases. The mean of the speech transmission index belong to the range of values: a) for the unoccupied church: $\overline{STI_{unocc}} = 0.52 \div 0.62$ and b) for the occupied church: $\overline{STI_{occ}} = 0.56 \div 0.7$ where intelligibility speech is classified from fair to good. Subjective intelligibility of speech (analyzed through subjective intelligibility of sentences, PB words and CVC logatoms determined by Standard IEC 60268-16), also significantly improves for the case of the occupied church. The mean of the subjective intelligibility of sentences belongs to the range: a) for the unoccupied church: $\overline{SI_{sent-unocc}} = 88.63 \div 96.93\ \%$, classifying speech intelligibility from bad to excellent, and b) for the occupied church: $\overline{SI_{sent-occ}} = 95.02 \div 99.2$ %, classifying speech intelligibility from good to excellent. The mean of the subjective intelligibility PB words belongs to the range: a) for the unoccupied church: $\overline{SI_{PBw-unocc}} = 87.99 \div 92.67\ \%$, classifying speech

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intelligibility as good and b) for the occupied church: $\overline{SI_{PBw-occ}}$ = 91.3 ÷ 95.14 %, classifying speech intelligibility from good to excellent. The mean value of the subjective intelligibility CVC logatoms belongs to the range: a) for the unoccupied church: $\overline{SI_{CVC-unocc}}$ = 61.16 ÷ 67.8 % and b) for the occupied church: $\overline{SI_{CVC-occ}}$ = 65.31 ÷ 77.35 %, classifying speech intelligibility from fair to good.

A statistically positive, moderate linear connection for unoccupied church, and statistically positive strong linear correlation for occupied church, between reverberation time and speech intelligibility (objective and subjective) was confirmed by correlation and regression analysis.

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