The Effect of Occupancy on Acoustic Parameters in a Concert Hall

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Abstract: - This paper determines the effect of occupancy of a concert hall on its acoustic parameters: time reverberation, speech transmission index, subjective speech intelligibility and music clarity, on the basis of a comparison of their values for an unoccupied and occupied hall Promenadikeskus, Pori, Finland. In the first part of this paper are shown the assessed values of the analyzed acoustic parameters according to the acoustic analysis of the impulse response of the concert hall and the estimation algorithms. In the second part of this paper, the results of the obtained acoustic parameters are shown graphically and in tabular and their comparative analysis performed. The results obtained were analyzed according to standards ISO 3382 and IEC 60268-16.

Key-Words: - Room Impulse Response, acoustic parameters, prediction, Standard.

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1 Introduction

In concert halls music, speech and acoustics are inseparable. There are held concerts and events that require, by their features, very different acoustic properties of the space, e.g. symphonic, piano, jazz and pop concerts, festivals of pop and folk music, theater performances, conferences etc. General conditions that have to be met in the halls for good quality listening including both listeners and performers are [1]: a) the room must not have noise (both internal and external), b) the sound must be loud enough at all points, c) there must not occur an echo in the hall, d) the volume must be approximately equal at all points, e) unwanted resonances must not occur in the hall.

A concert hall can be seen as a big resonance box of an instrument, where sound waves reflected off the walls and thereby initiate the phenomenon of reverberation. This phenomenon can be experienced subjectively as pleasant or irritating [1]. An objective classification is achieved with acoustical parameters extracted from the impulse response of the room.

The acoustic impulse response of the room gives an overall description of the alteration of a sound signal (bearer of musical or voice communication) which occurs on its way, and by its analysis it is possible to obtain almost all objective and subjective acoustic parameters of the facility: reverberation time, temporal focus, definition, clarity, speech intelligibility, etc.[2]. Thus, accurate impulse response measurements, already regulated by ISO 3382 standard [3] are desired for the assessment of acoustical properties.

This paper presents the effect of occupancy of a concert hall Promenadikeskus in the Pori (Finland) on objective acoustic parameters: reverberation time, speech transmission index, music clarity parameters and subjective intelligibility of speech.
The analysis is based on the data of impulse response of the concert hall, available on http://legacy.spa.aalto.fi/projects/poririrs/. The impulse responses were recorded at three locations of the sound source at multiple measurement points. Using software packages EASERA and Matlab, as well as and theoretical models, the following results were achieved for each location of the sound source and all measuring points: a) for an empty concert hall is determined: reverberation time by octaves $RT_{30unocc}$, mean value of the reverberation time by octaves $\overline{RT_{30unocc}}$, speech transmission index STI_{unocc}, mean value of the speech transmission index $\overline{STI_{unocc}}$, clarity of music $C_{80unocc}$ and mean value of the clarity of music $\overline{C_{80unocc}}$, b) provided for the fully occupied concert hall: the mean value of the reverberation time by octaves $\overline{RT_{30occ}}$, speech transmission index STI_{occ}, the mean value of the speech transmission index $\overline{STI_{occ}}$, clarity of music C_{80occ} and mean value of the clarity of music $\overline{C_{80occ}}$, c) for an empty concert hall is determined of the subjective intelligibility speech of sentences SI_{sent_unocc}, PB words SI_{PBw_unocc} and CVC

logatoms SI_{CVC_unocc}: and d) provided for the fully occupied concert hall mean value of the subjective intelligibility speech of sentences SI_{sent_occ}, PB words SI_{PBw_occ} and CVC logatoms SI_{CVC_occ}. The obtained values of these parameters are compared and analyzed in relation to standard values and certain conclusions were presented.

The work is organized as follows: Section II presents the estimation algorithms of the analyzed acoustic parameters and classification of the relationship between the revised speech transfer index (STI_r) and subjective speech intelligibility, Section III describes the experiment and the results are presented in tables and graphs, Section IV presents the result analysis, whereas Section V is the conclusion.

2 Acoustic Parameters for the Full Occupied Room

2.1 The Evaluation of the Parameters for the Full Room

The evaluation is performed for the following acoustic parameters: reverberation time, speech transmission index and music clarity.

2.1.1 Reverberation Time

The evaluation of the reverberation time for the full room RT_{occ} can be carried out using the following formula [4]:

$$RT_{occ} = RT_{unocc} - DT \tag{1}$$

where RT_{unocc} is estimated reverberation time for the empty room, and DT is Shulc's diffusiion time which is calculated using the equations from the Table 1 [5].

Table 1. Shulc's estimated values for *RT*

f (Hz)	*DT* (s)
125	0.510*RT*-0.708
250	0.605*RT*-0.867
500	0.668*RT*-0.929
1000	0.696*RT*-0.935
2000	0.694*RT*-0.889
4000	0.652*RT*-0.752

Just noticeable difference of the reverberation time values detected by the listeners is 1 JND=5% [3].

2.1.2 Speech Intelligibility

The evaluation of the speech intelligibility parameters for the full room STI_{occ} can be carried out using [6]:

$$STI_{occ} = STI_{unocc} + \Delta STI \tag{2}$$

STI_{unocc} is the index of the speech transmission for the empty room and ΔSTI je the value which is calculated using the following formula:

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

where RT_{unocc} is the reverberation time of the empty room and RT_{occ} is the reverberation time of the full room. These values are taken at f=2 kHz [6].

2.1.3 Music Clarity

The evaluation of the music clarity in the room, C_{80}, can be carried out using Baron's theory of sound decreasing in which the direct sound follows an exponential decrease in sound energy [7, 8]. Propagation time of the direct sound from the source to the receiver at the distance r is $t_D=r/c$, where c is the speed of sound.

For the room of the volume V integrated acoustic energy l for the time $t \geq t_D$, where $t \to \propto$, at certain location in the room is:

$$l(t) = 31200\frac{RT}{V}e^{-\frac{13.82t}{RT}} \tag{4}$$

where RT is thw reverberation time.

The evaluation of music clarity parameters in the room, C_{80}, includes three components of the received sound at the receiver position: the direct sound d (Eq. 5), the early reflected sound e with the delay less than 80 ms (Eq. 6) and the late reflected sound l with the delay of more than 80 ms (Eq. 7):

$$d = \frac{100}{r^2} \tag{5}$$

$$e = 31200\frac{RT}{V}e^{-\frac{0.04r}{RT}}\left(1 - e^{-\frac{1.11}{RT}}\right) \tag{6}$$

$$l = 31200\frac{RT}{V}e^{-\frac{0.04r}{RT}}e^{-\frac{1.11}{RT}} \tag{7}$$

where r is the distance between the receiver and the source. The estinated parameter of the sound clarity in the room C_{80} is:

$$C_{80} = 10\,log\frac{\int_{t_0}^{t_0-0.08} p^2(t)dt}{\int_{t_0+0.08}^{\propto} p^2(t)dt} = 10\,log\frac{d+e}{l} \tag{8}$$

2.2 The Evaluation of the Parameters for the Full Room

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 [9]. 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*) [10]. 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. [11]. 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 [11].

The relationship between the objective acoustic parameter *STI* and the speech intelligibility (expressed as percentage) is shown in Table I [9].

Table 1. Relatioship betwen *STI*, quality speech intelligibility to IEC 60268-16, and the speech intelligibility siales (SI_s), words (SI_w) and sentences (SI_{sent})

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

This correlation was made using intelligibility of [10]: 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 [9].

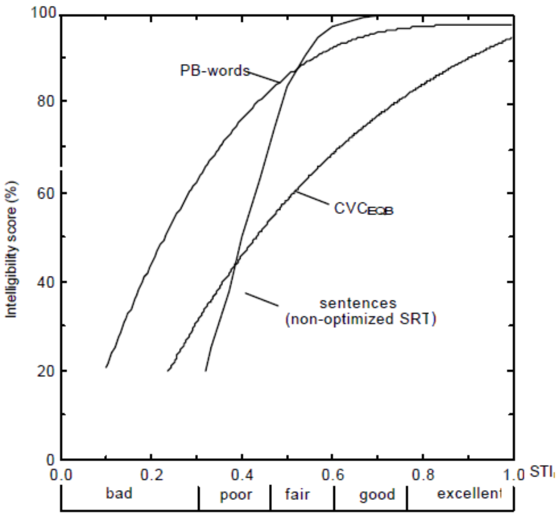


Fig.1. Classification of the relationship of speech intelligibility and *STI*.

3 Experiments

The evaluation of the acoustic parameters has been carried out for the Promenadikeskus concert hall in Pori, Finland, which is shown in the Fig.2.

Fig.2. Promenadikeskus concert hall in Pori.

According to the impulse responses [12] we determined the value of the objective acoustic parameters RT_{30}, *STI* and C_{80} for the unoccupied concert hall. Evaluation of these parameters was performed using theoretical models and Matlab program package.

For the analysis of acoustic parameters, we considered three locations of the sound source S and 4 (of 7) measurement locations, MP, the receiver, with the arrangement shown in Fig.3.

For the purpose of the room acoustic analysis, we calculated mean values of acoustic parameters considered for each position of the sound source at the measuring point and for each position of the sound source at all measuring points in the analyzed hall. The results are presented in tables and graphs.

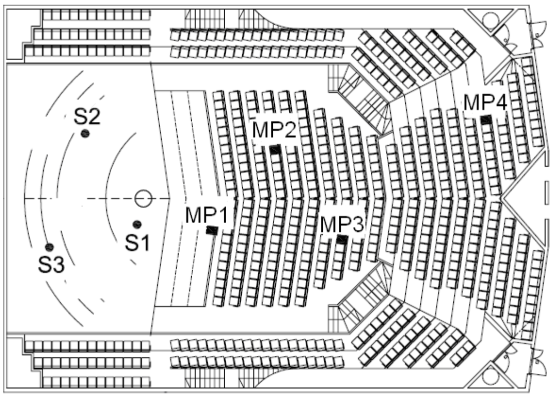


Fig.3. Location of sound sources (S1, S2 and S3) and measuring points ($MP1 \div MP4$).

3.1 The Basis

The impulse responses base contains audio recordings of the Pori Promenadikeskus concert hall impulse responses that have been recorded within the TAKU/VÄRE technical project [12]. The dimensions of the hall are: $33 \times 23 \times 15$ m. Total volume is approximately 9500 m^3 and capacity of about 700 people.

The responses were acquired using the IRMA measurement system. For all measurements, 48 kHz sampling rate and 16-bit A/D and D/A conversion were used. Two sound sources were utilized in the measurements. The measurements were performed using an omnidirectional loudspeaker DPA 4006 and a subwoofer. The impulse responses were measured using logarithmic sinusoidal sweep excitation. For measurements, the sweeps were synthesized in the time domain.

3.2 Results

Table 2 shows the values: a) the reverberation time $RT_{30unocc}$ and mean value of the reverberation times $\overline{RT_{30unocc}}$, for the unoccupied hall, b) of the Schultz diffusion, DT and c) mean value of the reverberation times $\overline{RT_{30occ}}$ for the occupied hall. Tables 3. – 5. show the values: a) the reverberation time (1 kHz, 2 kHz), the speech transmission index and the clarity for the music for the unoccupied and occupied hall and b) the mean values of these parameters for MP points for sound source locations S1, S2 and S3. The change in mean values of reverberation time at measuring points for the unoccupied and occupied concert hall for the sound sources positions S1, S2 and S3 is shown in Fig. 4.and Fig.5. The change in mean values of speech transmission index at measuring points for the unoccupied and occupied concert hall for the sound sources positions S1 and S2 is shown in Fig. 6. The values of this parameter for the sound source position S3 are shown in Fig. 7. The mean value of the clarity for music at the measured points for both unoccupied and occupied concert hall for sound source locations S1, S2 and S3 are shown in Fig. 8. Tables 6. – 8. show the mean values of subjective intelligibility speech of sentence PB words, and CVC logatoms for the unoccupied and occupied concert hall for the sound sources positions S1, S2, and S3, respectively. Classifications of the relationship of these parameters and the speech transmission index for the unoccupied and occupied concert hall for the sound sources positions S1 is given in Fig.9. and for S2 and S3 in Fig. 10.

Table 2. The values the reverberation time for unoccupied and occupied concert hall and Schultz diffusion time DT

Sound source	f (Hz)	$RT_{30unocc}$ (s)				$\overline{RT_{30unocc}}$ (s)	DT (s)	$\overline{RT_{30occ}}$ (s)
		MP1	MP2	MP3	MP4			
S1	125	2.71	2.59	2.83	0.76	2.22	0.42	1.8
	250	2.44	2.42	2.56	2.51	2.48	0.63	1.85
	500	2.45	2.4	2.43	2.47	2.44	0.7	1.74
	1000	2.33	2.34	2.36	2.36	2.35	0.7	1.65
	2000	2.12	2.13	2.12	2.13	2.13	0.59	1.54
	4000	1.72	1.72	1.72	1.76	1.73	0.38	1.35
S2	125	2.62	2.64	2.7	2.79	2.69	0.66	2.03
	250	2.41	2.36	2.54	2.57	2.47	0.63	1.84
	500	2.45	2.33	2.42	2.4	2.4	0.67	1.73
	1000	2.36	2.37	2.4	2.35	2.37	0.71	1.66
	2000	2.09	2.11	2.13	2.15	2.12	0.59	1.53
	4000	1.7	1.68	1.75	1.75	1.72	0.37	1.35
S3	125	2.71	2.66	1.04	2.8	2.3	0.47	1.83
	250	2.46	2.52	2.48	2.5	2.49	0.64	1.85
	500	2.4	2.39	2.44	2.41	2.41	0.68	1.73
	1000	2.38	2.36	2.37	2.41	2.38	0.72	1.66
	2000	2.13	2.1	2.14	2.14	2.13	0.59	1.54
	4000	1.73	1.7	1.7	1.76	1.72	0.37	1.35

Table 3. The values the reverberation time (1 kHz, 2 kHz), the speech transmission index and clarity for the music for the unoccupied and occupied concert hall for MP points for sound source location S1

MP	$RT_{30unocc}$ (1kHz) (s)	RT_{30occ} (1kHz) (s)	$RT_{30unocc}$ (2kHz) (s)	RT_{30occ} (2kHz) (s)	STI_{unocc}	STI_{occ}	$C_{80unocc}$ (dB)	C_{80occ} (dB)
1	2.33	1.64	2.12	1.54	0.515	0.671	-0.1	2.18
2	2.34	1.65	2.13	1.54	0.458	0.616	-1.83	-0.53
3	2.36	1.65	2.12	1.54	0.476	0.632	-2.7	-1.04
4	2.36	1.65	2.13	1.54	0.475	0.633	-2.03	-1.74

$\overline{RT_{30unocc}}$ (1kHz) (s)	$\overline{RT_{30occ}}$ (1kHz) (s)	$\overline{RT_{30unocc}}$ (2kHz) (s)	$\overline{RT_{30occ}}$ (2kHz) (s)	$\overline{STI_{unocc}}$	$\overline{STI_{occ}}$	$\overline{C_{80unocc}}$ (dB)	$\overline{C_{80occ}}$ (dB)
2.35	1.65	2.125	1.54	0.48	0.638	-1.67	-0.28

Table 4. The values the reverberation time (1 kHz, 2 kHz), the speech transmission index and clarity for the music for the unoccupied and occupied concert hall for MP points for sound source location S2.

MP	RT_{30uno} (1kHz) (s)	RT_{30occ} (1kHz) (s)	RT_{30unoc} (2kHz) (s)	RT_{30occ} (2kHz) (s)	STI_{unocc}	STI_{occ}	C_{80unoc} (dB)	C_{80occ} (dB)
1	2.36	1.65	2.09	1.53	0.467	0.619	-3.07	-0.67
2	2.37	1.66	2.11	1.54	0.474	0.628	-2.9	-0.59
3	2.4	1.66	2.13	1.54	0.458	0.616	-2.63	-1.45
4	2.35	1.65	2.15	1.55	0.476	0.635	-1.9	-1.74
	$\overline{RT}_{30unocc}$ (1kHz) (s)	$\overline{RT}_{30occ}$ (1kHz) (s)	$\overline{RT}_{30unocc}$ (2kHz) (s)	$\overline{RT}_{30occ}$ (2kHz) (s)	$\overline{STI}_{unocc}$	$\overline{STI}_{occ}$	$\overline{C}_{80unoc}$ (dB)	$\overline{C}_{80occ}$ (dB)
	2.37	1.655	2.12	1.54	0.469	0.625	-2.63	-1.11

Table 5. The values the reverberation time (1 kHz, 2 kHz), the speech transmission index and clarity for the music for the unoccupied and occupied concert hall for MP points for sound source location S3.

MP	RT_{30unoc} (1kHz) (s)	RT_{30occ} (1kHz) (s)	RT_{30uno} (2kHz) (s)	RT_{30occ} (2kHz) (s)	STI_{unoc}	STI_{occ}	C_{80unoc} (dB)	C_{80occ} (dB)
1	2.38	1.66	2.13	1.54	0.492	0.65	-1.87	-0.79
2	2.36	1.65	2.1	1.53	0.49	0.645	-2.5	-1.7
3	2.37	1.66	2.14	1.54	0.512	0.672	-2.8	-1.7
4	2.41	1.67	2.14	1.54	0.48	0.64	-3	-1.86
	$\overline{RT}_{30unoc}$ (1kHz) (s)	$\overline{RT}_{30occ}$ (1kHz) (s)	$\overline{RT}_{30unoc}$ (2kHz) (s)	$\overline{RT}_{30occ}$ (2kHz) (s)	$\overline{STI}_{unoc}$	$\overline{STI}_{occ}$	$\overline{C}_{80unoc}$ (dB)	$\overline{C}_{80occ}$ (dB)
	2.38	1.66	2.13	1.54	0.49	0.65	-2.54	-1.51

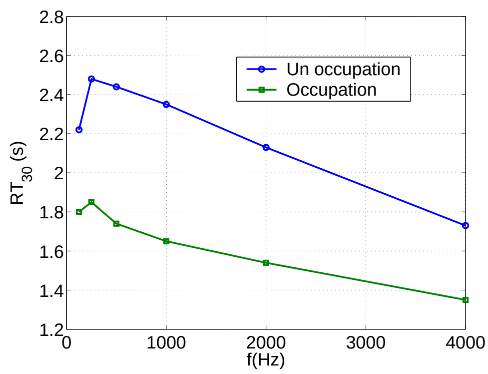


Fig.4. The mean value of the reverberation time at the measured points for unoccupied and occupied concert hall for sound source locations S1.

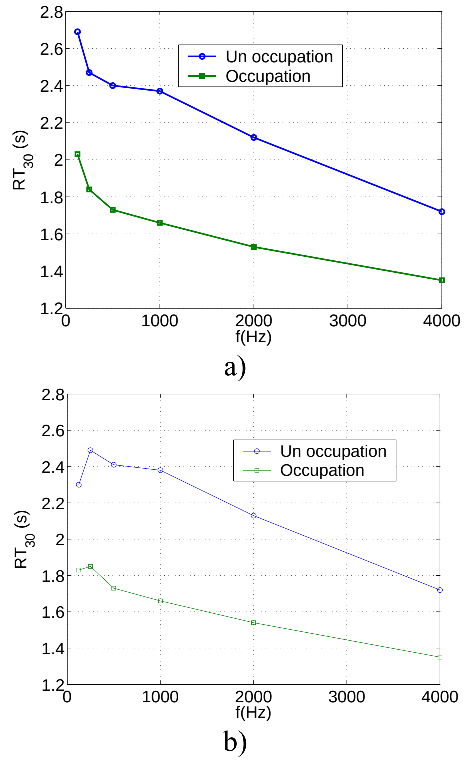


Fig.5. The mean value of the reverberation time at the measured points for unoccupied and occupied concert hall for sound source locations: a) S2 and b) S3.

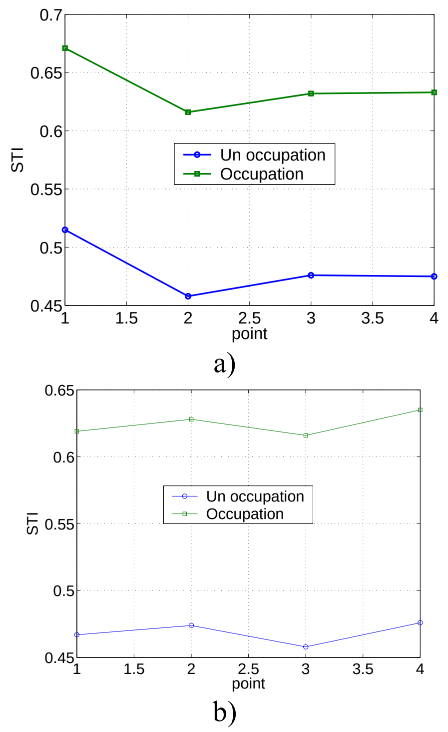


Fig.6. The mean values of speech transmission index at measuring points for the unoccupied and occupied concert hall for the sound sources position: a) S1 and b) S2.

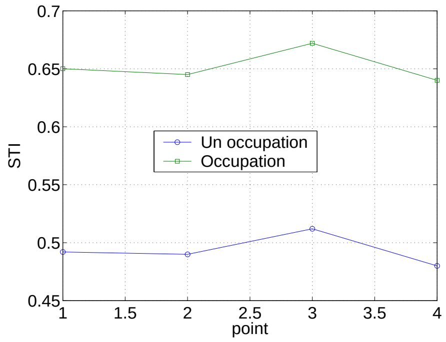
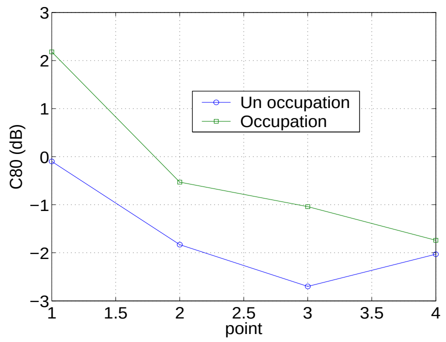
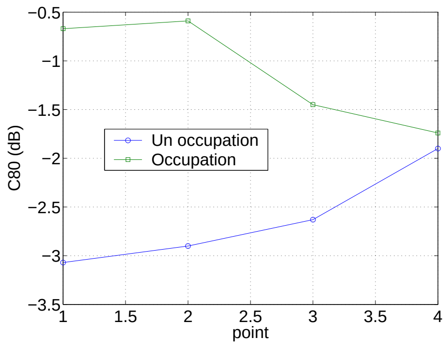


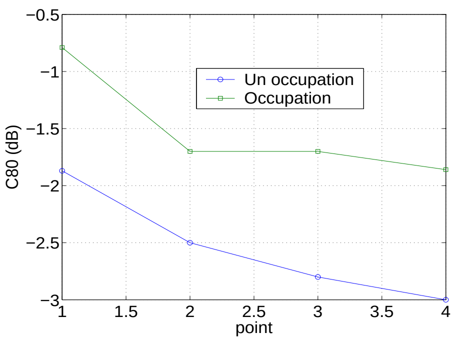
Fig.7. The mean value of speech transmission index at the measured points for unoccupied and occupied concert hall for sound source locations S3.



a)



b)



c)

Fig.8. The mean value of the clarity for music at the measured points for unoccupied and occupied concert hall for sound source location: a) S1, b) S2 and c) S3.

Table 6. The mean values of speech transmission index and the subjective intelligibility speech of sentence, PB words, and CVC logatoms for the unoccupied and occupied concert hall for the sound sources positions S1.

S1	$\overline{STI}_{unocc}$	0.48	SI_{sent_unocc} (%)	77
			SI_{CVC_unocc} (%)	55.5
			SI_{PBw_unocc} (%)	84.5
	$\overline{STI}_{occ}$	0.638	SI_{sent_occ} (%)	98.75
			SI_{CVC_occ} (%)	72
			SI_{PBw_occ} (%)	94
S2	$\overline{STI}_{unocc}$	0.469	SI_{sent_unocc} (%)	69.4
			SI_{CVC_unocc} (%)	53.1
			SI_{PBw_unocc} (%)	82.5
	$\overline{STI}_{occ}$	0.625	SI_{sent_occ} (%)	99
			SI_{CVC_occ} (%)	71.25
			SI_{PBw_occ} (%)	93
S3	$\overline{STI}_{unocc}$	0.49	SI_{sent_unocc} (%)	80
			SI_{CVC_unocc} (%)	57.2
			SI_{PBw_unocc} (%)	85
	$\overline{STI}_{occ}$	0.65	SI_{sent_occ} (%)	99.4
			SI_{CVC_occ} (%)	73.2
			SI_{PBw_occ} (%)	95

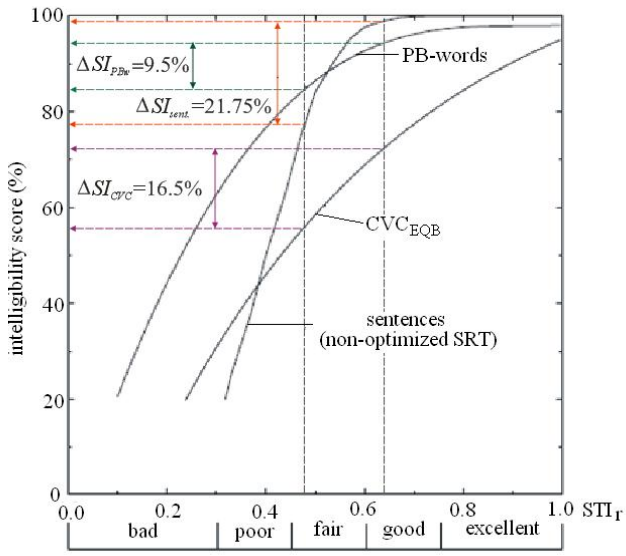
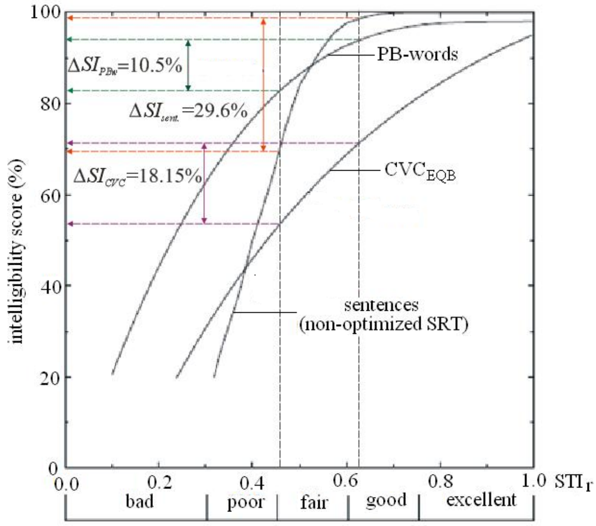
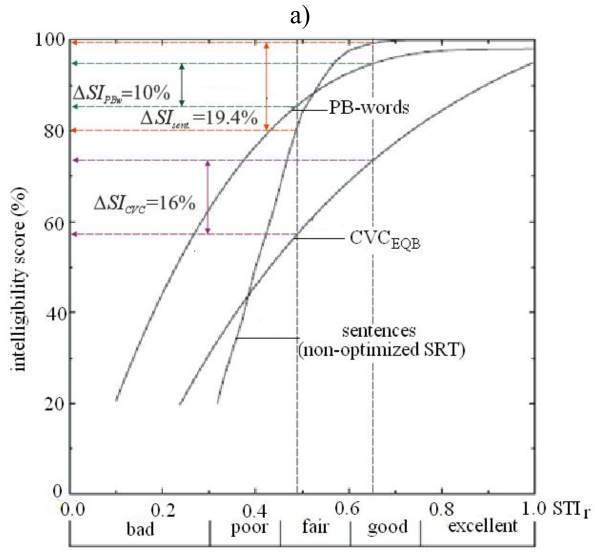


Fig. 9. Subjective intelligibility speech of sentences, PB words, and CVC logatoms for unoccupied and occupied concert hall for sound source locations S1.



a)



b)

Fig. 10. Subjective intelligibility speech of sentences, PB words, and CVC logatoms for unoccupied and occupied concert hall for sound source locations: a) S2 and b) S3.

4 The Results Analysis

Based on results shown in the Tables 2 – 6 and in the Figs. 4. - 10. is can draw the following conclusions:

1) The predicted mean values $\overline{RT_{30occ}}$, obtained by using the values to predict Schultz values (Table 1.), are for all sound sources and measuring points less than the mean values $\overline{RT_{30unocc}}$. The decrease in the values of the reverberation time is especially important at frequencies close to or equal to the frequency f = 1kHz because they are most important to the quality of speech intelligibility. At the positions of the sound source S1, S2 and S3, the decrease of the value of this parameter is $\overline{\Delta RT_{30}}$ (1kHz) $= \{0.7\,s, 0.715\,s, 0.72\,s\}$. At medium frequencies, the predicted mean values $\overline{RT_{30occ}}$ for all positions of the sound source are the same and values are in the range determined by the value of the optimum reverberation time for the concert hall standard: RT = 1.5 ÷ 2.2 s.

According to Barron's recommended reverberation time values for the occupied concert hall [7], the analyzed concert hall with the value for RT_{30srf} = 1.695 s is suitable for performing the following: early classical music (RT = 1.6 ÷ 1.8 s), opera (RT = 1.3 ÷ 1.8 s) and chamber music (RT = 1.4 ÷ 1.7 s).

2) At the positions of the sound source S1, S2 and S3 the increase in the mean value of index transmission is uniform: $\overline{\Delta STI}$ = {0.158, 0.156, 0.16}.

The mean values of this parameter for the unoccupied hall at all three positions of the sound source, $\overline{STI_{unocc}} = \{0.48, 0.469, 0.49\}$ are in the range determined by the values that represent the acceptable speech intelligibility: 0.45 ÷ 0.6. But the value of this parameter for an occupied hall, $\overline{STI_{occ}}$ = {0.63, 0.625, 0.65}, are in the range determined by the values that represent good speech intelligibility: 0.6 ÷ 0.75.

3) The predicted values of subjective speech intelligibility [9], for an empty concert hall, depending on the measurement locations of the sound source, determine the following quality of speech intelligibility: a) for the position of the sound source S1: bad intelligibility sentences (SI_{sent_unocc} = 77 %) and faire intelligibility CVC logatoms and PB words (SI_{CVC_unocc} = 55.5 %, SI_{PBw_unocc} = 84.5%); b) for the position of the sound source S2: bad intelligibility sentences (SI_{sent_unocc} = 69.4 %), and faire intelligibility CVC logatoms and PB words (SI_{CVC_unocc} = 53.2 %, SI_{PBw_unocc} = 82.5 %) and c) for the position of the sound source S3: bad intelligibility sentences (SI_{sent_unocc} = 80 %), and faire intelligibility CVC logatoms and PB words (SI_{CVC_unocc} = 57.2 %, SI_{PBw_unocc} = 85 %).

The predicted values of subjective speech intelligibility [9], for the occupied concert hall depending on the measurement locations of the sound source, determine the following quality of speech intelligibility: a) for the position of the sound source S1: excellent intelligibility sentences (SI_{sent_occ} = 98.75 %) and good intelligibility CVC logatoms and PB words (SI_{CVC_occ} = 72 %,

SI_{PBw_occ} = 94 %); b) for the position of the sound source S2: excellent intelligibility sentences (SI_{sent_occ} = 99 %), and good intelligibility CVC logatoms and PB words (SI_{CVC_occ} = 71.25 %, SI_{PBw_occ} = 93 %) and c) for the position of the sound source S3: excellent intelligibility sentences (SI_{sent_occ} = 99.4 %), good intelligibility CVC logatoms (SI_{CVC_occ} = 73.2 %) and excellent PB words (SI_{PBw_occ} = 95 %).

The increase in the value of the subjective speech intelligibility for the occupied hall at all sound source positions S1, S2, and S3 is: ΔSI_{sent} = {21.75 %, 29.6 %, 19,4 %}, ΔSI_{CVC} = {16.5 %, 18.15 %, 16 %} and ΔSI_{PBw} = {9.5 %, 10.5 %, 10 %}.

4) The estimated values of the medium index of music clarity in all positions of the sound source, for both the unoccupied is ($\overline{C_{80unocc}}$ = {-1.67 dB, -2.63 dB, -3 dB}), and occupied hall is ($\overline{C_{80occ}}$ = {-0.28 dB, -1.11 dB, -1.86 dB}). The predicted average values of music clarity meet the criteria of optimum values for orchestral music: (0 $\div$ -3)dB.

The increase in the mean value of the index of music clarity for the occupied hall at all sound source positions S1, S2, and S3 is $\overline{\Delta C_{80}}$ = {1.39 dB, 1.52 dB, 1.14 dB}.

5 Conclusion

The effect of the occupancy of a concert hall on its acoustic parameters: the echo of time, the index of speech transmission, subjective intelligibility of speech and clarity of music, it was performed on the basis of a comparison of their values for an unoccupied and occupied concert hall.

Additional sound absorption due to the presence of people in the concert hall led to a decrease in the mean value of the reverberation time for $\overline{\Delta RT_{30}}$ (1kHz) $\approx$ 0.7 s, increase in the mean value of the speech transmissionindex for $\overline{\Delta STI}$ $\approx$ 0.16 and the maximum increase in the mean value of music clarity of $\overline{\Delta C_{80}}$ = 1.52 dB. Concert hall occupancy also influenced the increase in subjective speech intelligibility: sentences ($\overline{\Delta SI_{sent}}$ = 23.58 %), CVC logatoms ($\overline{\Delta SI_{CVC}}$ = 16.88 %), and PB words ($\overline{\Delta SI_{PBw}}$ = 10 %). This contributed to the ranking of this concert hall as being excellent for the subjective intelligibility of sentences and good for the subjective intelligibility of CVC logos and PB words.

The predicted values of acoustic parameters also confirmed the fact that this concert hall has been acoustically designed for early classical, opera and chamber music.

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