CHARACTERISATION OF ACOUSTIC BEHAVIOUR IN SMALL AUDITORIUMS

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ABSTRACT

This paper aims to characterise and compare the acoustical behaviour of small auditoriums of various sizes and dimensions. Characterisation is accomplished by the measurement of sound quality parameters such as reverberation time, early decay time, clarity, deutlichkeit, etc. The measured values are compared with those yielded by mathematical models based on prediction techniques in order to obtain some conclusions about the initial assumptions and prediction methods.

INTRODUCTION

The work presented here is part of a larger research programme of investigation where the main objective is the study and analysis of the acoustic conditions of small auditoriums for different purposes. Our idea is to evaluate the acoustic quality of small auditoriums using different methods and techniques and to compare the results with in situ measurements. At this moment we have about twelve rooms on evaluation, three of them for speech communication (*conference rooms*), three for classic music, and the others for multi-purposes such as cinema, theatre, music, etc. This paper presents the results we obtain for the three analysed conference rooms, using only the Catt-Acoustics software and in situ measurements.

We are just giving the first steps in this area and, for this initial approach, we have chosen auditoriums basically presenting the same characteristics and finishing materials. This fact makes, in a certain way, the analysis and comparison of the results easier.

CASE STUDIES

The auditoriums analysed have materials with similar acoustic absorption and diffusibility. From this analogy it will be possible to evaluate the coherence of the acoustical characteristics for each one of the diverse materials. All the auditoriums belonged to a school of higher education and are basically meant to speech communication without any system of sound amplification. The parallelepipedic shape is the basic pattern. The auditorium of larger dimensions is the only one exception with a floor presenting different levels.

Relative to the features of absorption and diffusibility of the interior surfaces, the values that had been considered are presented in Tables 1, 2 and 3. The values had been obtained directly from diverse bibliographical references and from elements supplied by the author of the prediction software. Table 1 refers to the values of the absorption coefficients for the interior surface materials of all auditoriums.

TABLE 1
SABINE SOUND ABSORPTION COEFFICIENTS OF COATING MATERIALS

Surfaces	**Frequencies**					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Linoleum on concrete	0.01	0.01	0.02	0.02	0.03	0.03
Plaster smooth finish on brick	0.01	0.02	0.02	0.03	0.04	0.05
Ordinary glass in a window-frame	0.04	0.04	0.03	0.03	0.02	0.02
Veneer wooden door	0.25	0.22	0.17	0.09	0.06	0.06

The chairs were similar in all the auditoriums. They have padded seats and backs, and textile covering and finishing. To consider the sound absorption coefficient of the chairs, some difficulties in getting direct values from the literature had been verified, because the available information was found insufficient. The procedure adopted in this case consisted in considering the average values relative to 9 types of padded chairs with similar features to the existing ones. In table 2 we consider the values for the absorption coefficients adopted in the prevision method. With these values we intend to consider two different situations. In the first one, we assumed the audience as a simple plane in the floor. In the other situation, we assume the audience as a volume with an upper and edges surfaces.

For the coating materials and chairs, the values used in the prediction method for the diffusion coefficients are presented in Table 3.

TABLE 2
SABINE SOUND ABSORPTION COEFFICIENTS OF CHAIRS

Type	Frequencies					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Considering only audience surface (auditorium SB)	0.17	0.35	0.70	0.75	0.75	0.75
Considering audience surface and edges (auditorium S53 and S56)	0.09	0.18	0.37	0.39	0.39	0.39

TABLE 3
DIFFUSION COEFFICIENTS

Surfaces/chairs	Frequencies					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Linoleum on concrete	0.10	0.10	0.10	0.10	0.10	0.10
Plaster smooth finish on brick	0.10	0.10	0.10	0.10	0.10	0.10
Ordinary glass in a window-frame	0.10	0.20	0.30	0.40	0.50	0.60
Veneer wooden door	0.10	0.10	0.10	0.10	0.10	0.10
Chairs	0.30	0.40	0.50	0.60	0.70	0.70

As a sound source we considered one octave-band speech spectrum at 1m distance with the Lp1m values presented in the next table. Also in the next table we present the background noise level average, resulting from measurements carried out in all three auditoriums, used in the prevision method. All the auditoriums were empty when measured and analysed.

TABLE 4
SOUND SOURCE PRESSURE LEVEL AT 1m DISTANCE AND BACKGROUND NOISE DURING MEASUREMENTS

Characteristics	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Lp1m of sound source (dB)	55	61	65	632	56	51
Background Noise (dB)	27	29	34	24	23	20

MEASUREMENTS

The measurements were carried out in various steps. The first one consists not only in the evaluation of dimensional characteristics, relative position of windows and access door, but also the feature, shape and seat location. In Table 5 the main dimensions are presented. In a second phase RASTI was measured to evaluate the quality of speech communication with respect to intelligibility of the different auditoriums. The measurement had been made taking into account a certain background noise. For the prediction method we used the real background noise average referred to in Table 4, evaluated during the RASTI index measurements. The RASTI measuring system is based in a Brüel Kjær Speech Transmission Meter type 3361. The results are presented in Table 6.

TABLE 5
AUDITORIUMS CHARACTERISTICS

Auditorium	N.º of seats	Volume V (m^3)	Internal surface S (m^2)	Relation V/S (m)	Major diagonal (m) (Rectangular rooms)	Ideal TR (s)
SB	102	604	511	0.85	18.05	0.70 – 0.80
S53	90	335	355	1.06	16.55	0.60 – 0.70
S56	45	166	200	1.20	11.00	0.55 – 0.65

TABLE 6
RASTI MEASURED VALUES

Auditory	Positions								Average	SCALE
	1	2	3	4	5	6	7	8		
SB	0.48	0.54	0.50	0.46	0.48	0.44	0.42	0.47	**0.47**	**FAIR**
S53	0.61	0.56	0.54	0.58	0.48	0.52	0.55	0.51	**0.54**	**FAIR**
S56	0.52	0.52	0.54	0.53	0.53	-	-	-	**0.53**	**FAIR**

In the third and last phase, first we evaluated three 60 dB decay times: T30, T20 and EDT (*Early Decay Time*) derived from the decays measured in the auditoriums, and then three room-acoustic parameters with an omnidirectional sound source: C (*Clarity – Early-to-late Sound Index*), D (*Deutlichkeit – Early Energy Fraction*) and the Ts (*Centre Time*). All this measurements had been made for octave-bands between 125Hz and 4kHz. In the next table we present the parameters average, taking into account the different receiver positions.

PREDICTION METHOD

For acoustic prediction we used software based on the Randomize Tail-corrected Cone-tracing (RTC) – CATT–Acoustics - developed by CATT (*Computer Aided Theatre Technique*) from Gothenburg - Sweden. The main programme integrates several aspects such as prediction, binaural post-processing, and addition of multiple sources, source directivity and surface proprieties management and several other functions. To use the prediction software it is necessary to define the room geometry (*the corner coordinates and the plane definitions*) as well as the receiver's position and the source data and to define the absorption and diffusion factors. All the calculations are made for six octave-bands (*125Hz to 4kHz*).
The major problem in the software application consists in the definition of the absorbing/diffusing proprieties for the auditoriums internal surfaces and for the individual seats.

In a general way, the geometry input, source definition and receiver position do not present any difficulty.

TABLE 7
ACOUSTICAL MEASURED PARAMETERS

Parameters	Frequencies						Obs.
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	
Auditorium SB							
T30 (s)	6.65	4.35	2.33	1.77	1.57	1.31	8 positions
T20 (s)	7.08	4.54	2.29	1.76	1.59	1.26	
EDT (s)	6.73	4.47	2.18	1.70	1.52	1.14	
C (dB)	-5.9	-3.8	0.9	2.5	3.1	5.2	
D	0.17	0.24	0.45	0.55	0.54	0.65	
Ts (ms)	451	301	118	93	84	57	
Auditorium S53							
T30 (s)	4.17	3.43	1.31	1.28	1.33	1.14	8 positions
T20 (s)	4.28	3.33	1.34	1.28	1.31	1.15	
EDT (s)	4.41	2.8	1.25	1.21	1.23	1.06	
C (dB)	-5.0	-2.0	3.1	3.2	3.3	4.1	
D	0.14	0.29	0.56	0.53	0.54	0.57	
Ts (ms)	324	1.76	79	79	77	68	
Auditorium S56							
T30 (s)	3.66	2.94	1.44	1.33	1.31	1.15	6 positions
T20 (s)	3.87	2.86	1.42	1.33	1.30	1.14	
EDT (s)	3.82	2.47	1.41	1.31	1.26	1.10	
C (dB)	-6.2	-2.7	0.9	1.8	1.9	2.6	
D	0.12	0.24	0.40	0.43	0.43	0.46	
Ts (ms)	274	179	106	93	92	83	

As the author refers in the user's manual the underlying theory is the geometrical acoustics, the reason why for small rooms only the upper octaves 1, 2 and 4 kHz will be well predicted. In the resulting analysis we will try to verify this aspect.

RESULT ANALYSIS

The most significant results obtained from the simulation and the corresponding deviations from the measured values can be synthetized in the next two tables. In a general way, we can refer to the better results obtained for the smallest auditoriums (*S53 and S56*). For auditorium SB we verify for all acoustic parameters significant deviations relative to the values obtained from the measurements made in the same auditoriums. In what concerns the reverberation time, for auditoriums SB and S53 the most significant deviations from the measured values occur in the octave-bans between 500Hz and.2KHz. On the contrary, we verify for the same octave-bands, the closeness between measured and calculated values for the auditorium S56. In a general way, the obtained reverberation times from the calculation are higher then the real ones. For the considered Sabine sound absorption coefficients of coating materials we also verify that the decay times obtained from the Randomize Tail-corrected Cone-tracing (*RTC*) method are more correct than the values obtained from classical methods (*Sabine e Eyring*). For this reason we can confirm the author note [1] about the difference between the two methods, because all three auditoriums have simply shaped halls with uneven absorption distribution (*halls, ceilings and floors on one side and unoccupied seats on the other side*) and without diffusely reflecting walls or ceilings.

TABLE 8
RASTI PREDICTABLE VALUES

Auditorium		Positions 1	2	3	4	5	6	7	8	Average
SB	**Pred. value**	0.47	0.47	0.49	0.41	0.41	0.42	0.44	0.42	**0.44**
	Deviation (%)	- 2,1	-13,0	-2.0	-10,9	-14,5	-4,5	+4,8	+10,6	**6,3**
S53	**Pred. value**	0.58	0.62	0.59	0.55	0.54	0.53	0.55	0.55	**0.56**
	Deviation (%)	-4,9	+10,7	+9.2	-5,2	+12,5	+1,9	0,0	+7,8	**3,6**
S56	**Pred. value**	0.55	0.56	0.54	0.52	0.53	-	-	-	**0.54**
	Deviation (%)	+5,8	+7,6	0,0	-1,9	0,0	-	-	-	**1,9**

TABLE 9
PREDICTABLE ACOUSTICAL PARAMETERS

Parameters		Frequencies 125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	Average error
Auditorium SB								
T30 (s)	Pred. value	7,0	4,2	3,0	2,4	2,2	1,7	24 %
	Deviation (%)	+4	-4	+30	+33	+38	+31	
T15 (s)	Pred. value	7,3	4,2	2,9	2,4	2,3	1,6	22 %
	Deviation (%)	+3	-7	+26	+33	+44	+23	
EDT (s)	Pred. value	7,5	4,2	2,8	2,4	2,1	1,6	29 %
	Deviation (%)	+12	-7	+27	+41	+40	+45	
C (dB)	Pred. value	-7,9	-4,5	-1,8	-0.9	-0.1	1.5	
	Deviation (%)							
D	Pred. value	0,10	0,20	0,31	0,35	0,39	0,46	30 %
	Deviation (%)	-39	-18	-31	-36	-28	-29	
Ts (ms)	Pred. value	551	293	185	156	137	100	48 %
	Deviation (%)	+22	-3	+57	+68	+63	+75	
Auditorium S53								
T30 (s)	Pred. value	3,8	2,6	1,9	1,5	1,7	1,2	18
	Deviation (%)	-9	-23	+46	+15	+8	+9	
T15 (s)	Pred. value	3,9	2,4	1,7	1,5	1,3	1,1	15
	Deviation (%)	-9	-27	+31	+15	0	-8	
EDT (s)	Pred. value	4,1	2,4	1,5	1,4	1,2	1,0	10
	Deviation (%)	-7	-14	+15	+17	0	-9	
C (dB)	Pred. value	-4,1	-0,7	2,6	3,2	3,9	5,1	
	Deviation (%)							
D	Pred. value	0,19	0,33	0,49	0,52	0,55	0,61	12
	Deviation (%)	+38	+12	-12	-2	+2	+7	
Ts (ms)	Pred. value	291	160	94	84	74	61	10
	Deviation (%)	-10	-9	+19	+6	-4	-10	
Auditorium S56								
T30 (s)	Pred. value	3,5	2,1	1,4	1,4	1,3	1,0	5
	Deviation (%)	-5	-28	0	+8	0	-17	
T15 (s)	Pred. value	3,6	2,1	1,6	1,4	1,3	1,0	11
	Deviation (%)	-8	-28	+14	+8	0	-9	
EDT (s)	Pred. value	3,7	2,2	1,5	1,4	1,2	1,0	8
	Deviation (%)	-3	-12	+7	+8	-8	-9	
C (dB)	Pred. value	-5,2	-2,0	0,9	1,7	2,4	3,7	
	Deviation (%)							
D	Pred. value	0,16	0,28	0,42	0,46	0,50	0,56	18
	Deviation (%)	+37	+18	+6	+8	+16	+23	
Ts (ms)	Pred. value	278	161	103	91	81	66	8
	Deviation (%)	+1	-10	-3	-2	-12	-20	

For the RASTI index the results obtained from the prevision model are, in a general way, very close to the measured ones.

For the remaining acoustic parameters (Clarity, Deutlichkeit and Centre Time) local measurements, we noticed that the receivers with the worst results are obtained at an audience-central position. In the prediction model these receptors are situated in the most distant places relative to the sound source. This fact could be in part explained by the fact that the central position receivers can be influenced by multiple reflected sound waves at the ceiling and bottom wall.

The calculated values for the acoustic parameters Clarity, Deutlichkeit and Centre Time reveal a significant approach to the measured ones. The deviations are not very significant and are no more than a consequence of the calculated decay curves. For the higher frequencies (≥ 1KHz) we have a good approach between the measured and calculated values. Clarity is the parameter that presents bigger dispersion.

CONCLUSIONS

Apparently, by using the simplified prediction model, and for all analysed auditoriums, we couldn't achieve a good fit with the experimental results, not only in the lower octave bands, but also in the upper octaves 1, 2 and 4 kHz. However, the related results could not be regarded as representative of the analysed auditoriums. One probable reason may consist in inaccurate absorption/diffusion coefficients of the surface coatings, no previous measurements of absorption coefficients had been carried out. Another possibility could be the acoustic behaviour considered for the seats, the absence of wall details or the ceiling lamps in the geometry description.

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