THE BENEFIT OF A CARMEN® ELECTROACOUSTIC SYSTEM IN THE AYLESBURY THEATRE

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1 INTRODUCTION

The 1200 seat Aylesbury Waterside Theatre opened in October 2010. It was designed by Arts Team of RWHL architects with acoustic design by Arup. The theatre needed to be flexible enough to accommodate events and performances from pop to classical music, as well as opera and theatre. For this reason Arup specifications included the requirement for an electroacoustic system. After tendering, the CARMEN® electroacoustic enhancement system, designed by CSTB, was chosen and installed.
This paper presents the design and results of the installation of the CARMEN® system in the Aylesbury Waterside Theatre. It also presents the passive acoustic design for amplified music and how the extension with the electroacoustic system was envisioned and achieved. It details the CARMEN® electro-acoustic design and explains the tuning and fine-tuning session with musicians. Measurement results and the subjective evaluation with the feedback of acousticians and musicians are presented.

2 PASSIVE ACOUSTIC DESIGN

The primary function of the theatre was to be a touring house, presenting musicals, pop concerts and light entertainment, all with use of amplified sound. The theatre's use for opera, ballet and classical concerts was of lower priority in terms of importance and frequency of events. The form of the theatre includes large forward facing balconies and all the stalls seating can be removed on wagons to provide a flat floor. This suits 'end on' amplified sound productions rather than intimate music or speech events where the audience are wrapped closely around the performance.
The demands of a truly multi-purpose venue are challenging acoustically. Most halls where the natural acoustic for classical music is given priority, the hall is built to 'concert hall' acoustic volume and reverberance is reduced for other uses. In the case of Aylesbury this would have meant variable sound absorption (and it limitations on the room acoustic in terms of frequency balance, clarity and lateral energy) would have been used for the majority of events.
The decision was made early on that the theatre would have a natural acoustic beneficial to amplified music, and the acoustic would be electronically enhanced for music events. Reverberance was designed to be about 1.1 s mid frequency unoccupied, with limited base rise. This limited the volume of the room required (actual volume 8800 m^3), saving building height, overall cost and cost for physical variable elements. The seating is well upholstered and the upper levels have broadloom carpet throughout. Otherwise, wall finishes are plastered block or timber; the characteristic stacked timber providing a high degree of sound diffusion. A curved reflector over the 5.5 m deep forestage (or pit) provides physical support to the acoustic for the performers.

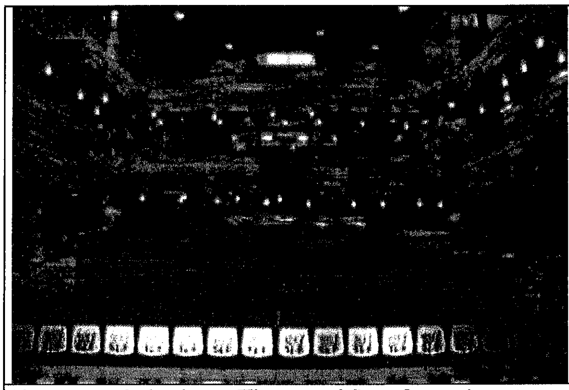

Figure 1: Aylesbury Theatre: View from the stage

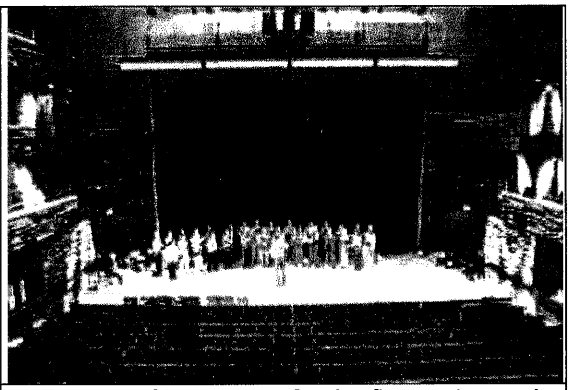

Figure 2: Choir set-up for the fine-tuning and subjective evaluation

3 THE ELECTROACOUSTIC BRIEF

The electroacoustic enhancement system was required to achieve the following acoustic design parameters in 90% of the seats for three of the settings. At the time of commissioning, a further setting for speech was added.

Parameter	Opera / Ballet	Orchestral	Choral
Reverberation time	1.3 - 1.6 s	1.8 - 2.1 s	2.1 - 2.3 s
Reverberation time at 125 Hz	1.5 s	2.25 s	2.6 s
Early decay time	1.25 s	1.7 s	2.0 s
Clarity index, C_{80}	> -1 dB	> -2 dB	
Early lateral energy fraction	0.18 - 0.35	0.18 - 0.35	
Loudness index	4 - 7 dB	4 – 7 dB	4 – 7 dB

Table 1: Range for acoustic parameters when measured in the empty theatre, mid frequency (500 Hz to 1 kHz unless otherwise stated)

To achieve this performance, the system needed to provide support to early reflections, as well as adding reverberant energy. It was also specified that the directional characteristics of the sound must remain true and the enhanced sound must be completely natural, as judged by a listening panel. There had to be no noise generated by the system and no amplification of noise such as ventilation. The system was specified to be completely separate from the house sound system.

4 DESIGN OF THE SYSTEM

The proposed system is a CARMEN® system which has been available since 1999[1]. It is a regenerative system which is based on the virtual wall principle[2]. The local reaction of the cells is achieved by placing microphones close to the corresponding loudspeaker[3].

The system in the Aylesbury Theatre is composed of 28 CARMEN® cells each composed of a microphone and a loudspeaker. The exact position of each cell in the theatre has been carefully designed through common study with the architectural team. The positions are shown in Figure 3 and Figure 4. Six locally reacting cells are positioned on each side of the lateral walls to provide lateral energy and reverberation to the public. They contribute to reinforcement of the listener envelopment. Seven locally reacting cells in the ceiling above the audience provide late reverberation to the public and reinforce the reflections coming from the ceiling. They enhance late reverberation. Three locally reacting cells on the movable forestage reflector provide early reflections and reverberation to the public at the front of the stalls. They contribute to give support to the performers on stage and in the orchestra pit. These cells are equipped with a cable reeler that allows easy movement of the forestage reflector between the theatre position for ballet, drama and opera and the concert position at a lower level. Six cells under the 1st and 2nd balcony ceilings provide early reflections and reverberation to the public under the balcony at the rear of the stalls and of the 1st balcony. They contribute to better coupling of these areas to the main volume. In addition, 2 directional forestage microphones are situated approximately 10 m from the stage opening, hanging from the lighting bridge. In order to achieve voice reinforcement effects, the microphones capture the direct sound coming from the stage and the signals, adequately delayed and filtered, are sent to some of the loudspeaker cells in the theatre in order to enhance the direct sound and therefore the speech intelligibility in a very natural way. This feature is useful for speech (drama) or singing performances (opera). It complements the function of the locally reacting cells. No electroacoustic orchestra shell was designed, in order not to clutter the stage house where complete flexibility is needed to be able to host multi-purpose performances.

The tuning of following five presets was agreed with the client, the acoustician and the end-user:

Preset n°	Description	Use
0	System off: RTmid = 1.1 s	Conference, Amplified Music
1	Stage reinforcement for voices RTmid almost unchanged: 1.1 s	Speech Drama
2	Medium RTmid increase: 1.6 s Homogeneous effect	Ballet (orchestra in the pit)
3	Medium RTmid increase: 1.7 s Stage reinforcement for voices	Opera (orchestra in the pit)
4	Large RTmid increase: 2.0 s Homogeneous effect	Symphony
5	Very large RTmid increase: 2.2 s Homogeneous volume effect	Chorus

Table 2: List of presets tuned for the Aylesbury Theatre

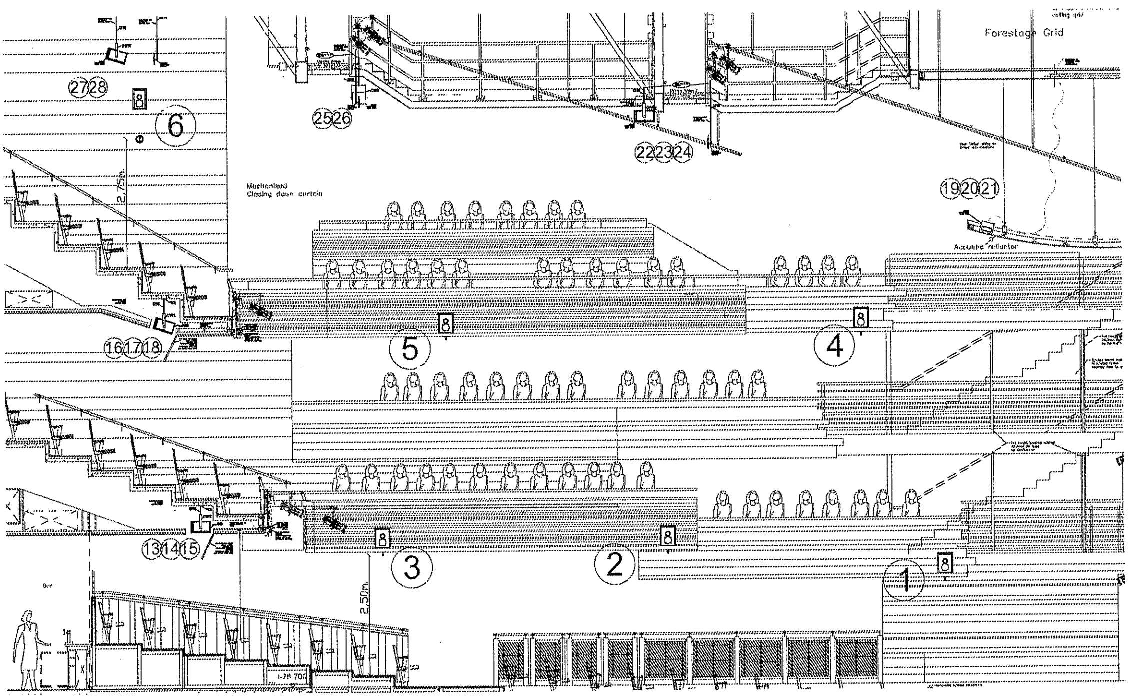

Figure 3: Position of the cells n° 1 to 6, n° 13 to 28

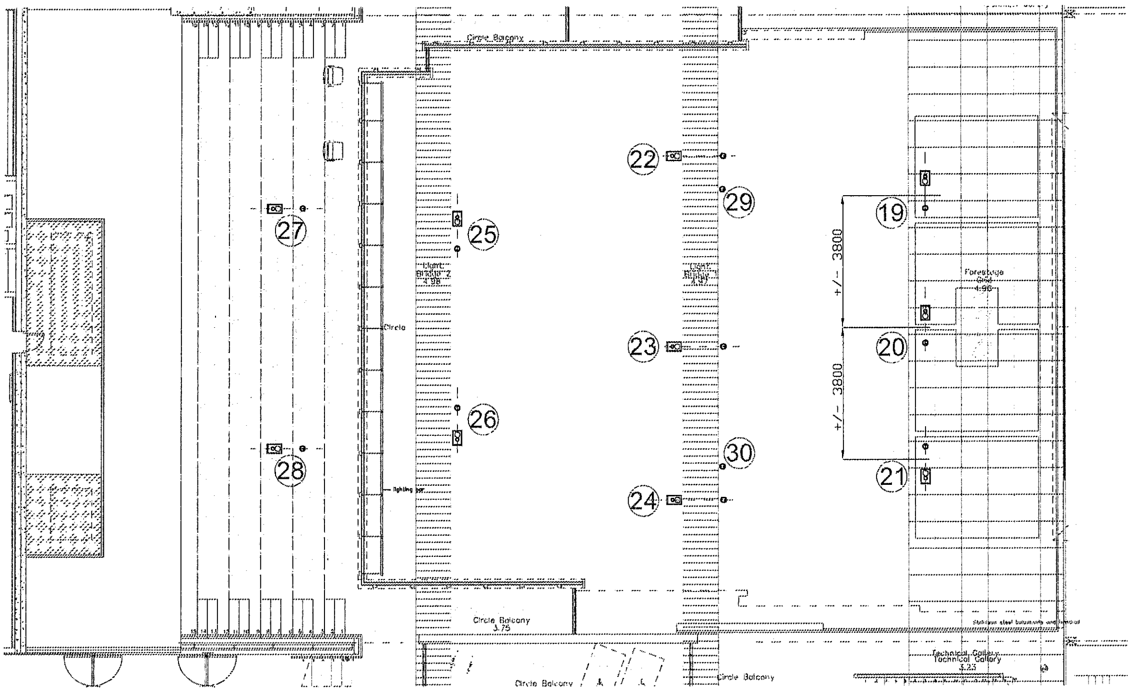

Figure 4: Position of the cells n° 19 to 28 and forestage microphones n° 29 and 30

5 PASSIVE ACOUSTIC RESULTS

On completion of the auditorium, the room acoustic was measured. With the safety curtain down, the mid frequency reverberation time unoccupied was 1.14 s, rising to 1.39 s at 125 Hz. With the safety curtain up, the reverberation time increased to 1.4 s mid frequency and 2 s at 125 Hz. At the time only the house curtain and three sets of borders were hanging in the flytower. More sound absorption would normally be expected for any staged production. These results informed the final tuning of the CARMEN® system.

6 INSTALLATION AND TUNING OF THE CARMEN® SYSTEM

The installation was done in several steps. First, as soon as the containment was installed in the building, cables were pulled from the CARMEN® rack location in the follow spot room to every microphone and loudspeaker position. Once the site was relatively free from dust, the CARMEN® rack with the electronics and the loudspeaker were delivered on site, positioned at their location and connected with the cables. The microphones with very low intrinsic background noise were installed just shortly before the tuning session to avoid damage or disappearance.

Because the microphones of the system pick up the sound in the reverberant field, the Carmen® system needs to be specifically adjusted for each hall. This is achieved through a tuning session which takes into account the microphone and loudspeaker exact positions in the auditorium. The tuning of the system requires complete silence on stage and in the auditorium, which is not easy to achieve on a construction site.

The commissioning of a system follows a very systematic procedure. Once the proper functioning of the installed hardware has been checked, each cell is tuned one by one. The basic stability of the system is achieved by using an automatic stabilization algorithm of the system developed by CSTB. Cells are then grouped into virtual walls and the parameters for each virtual wall are adjusted. The reverberation provided by the system is then increased slowly until the specifications are achieved.

The different presets are created in order to achieve the best results for a specific performance type (theatre set-up and type of performers). Each preset can provide a different sound colour of the hall, by for example adjusting the frequency response of the system. For the Speech drama and the Opera preset some sound picked up by the forestage microphones is reemitted through some loudspeakers of the system in order to increase intelligibility. The preset tuning is done manually. No automatic tuning exists because the subjective listening to the effect of the system on the acoustic field is more precise than existing measurable parameters.

A fine-tuning session was organised directly after the tuning in the presence of professional and amateur performers. Each preset is fine-tuned with the corresponding theatre set-up (reflector position, orchestra pit or forestage, etc.) and performers. Careful listening to the homogeneity, frequency balance of the sound, as well as arrival time of direct sound and reflections results in high quality presets.

The Speech drama preset was fine-tuned with a professional actor. The level and delays of the reemitted sound were adjusted to achieve a very natural sound for the voice of the actor, while being intelligible in the furthest seats of the theatre. For the Ballet and Symphonic preset, the orchestra was small, but all symphonic instruments were represented (violins, viola, cello, double bass, oboe, flute, clarinet, bassoon, French horn, trumpet, trombones, percussion, etc.). For the Ballet preset, the orchestra was seated in the orchestra pit and one of the goals was to fill the complete theatre with music rather than confining the sound to the pit. The repertoire allowed listening to the timbre of each instrument over the full orchestral frequency range. A professional female opera singer on stage was added to the orchestra in the pit for the Opera preset. Attention was given particularly to the sound balance between the singer and the sound intensity of the orchestra so to insure the good intelligibility of the singing. To fine-tune the Chorus preset an amateur choir of approximately 30 singers was appointed and the frequency balance and clarity of the sound adjusted.

Discussions with the conductors of the orchestra and choir provided feedback on the global ensemble sound impression. Discussions with musicians revealed a real fear of the impact of the electroacoustic system on their instrumental sound.

7 SUBJECTIVE EVALUATION

A subjective evaluation session was organized, including a contractual listening panel, composed of 5 people in total. Adjustments to the system tuning for each setting were made in response to the listening panel feedback. The Symphony and Chorus presets are finally slightly lower in RT than requested in the brief. These presets were lowered after requests of the subjective evaluation panel as the reverberance and strength of the sound were starting to become out of proportion with the visual size of auditorium and performers. The listening panel judged the sound to be completely natural and true to the source location and directional characteristics from the start.

8 MEASUREMENT RESULTS

Objective measurements were carried out once the different presets were tuned and the fine-tuning validated with the listening panel. The measurements of the room acoustic criteria in the unoccupied auditorium were carried out with and without the system according to ISO 3382-1[4]. The stage, the proscenium or the orchestra pit, were set up according to the different CARMEN® acoustic preset. The loudspeaker (Genelec 1031 AM speaker) was placed in the centre of the stage at 3 m from the front edge, or in the middle of the orchestra pit for Ballet and Opera presets. A multi-directivity microphone (Sennheiser MKH80-P48) was positioned in 11 positions (5 at the ground floor, 3 at the first balcony and 3 at the upper balcony). The impulse response measurements were made using the MLS Hadamard technique and the calculation of the criteria was derived from a specialised computer programme following the standard ISO 3382-1. Results are shown in the following table and graphics (Figure 5 to Figure 7):

	Preset n°	0	1	0	2	3	0	4	5
	Preset name	Passive (no forestage & curtain up)	Speech Drama	Passive (orchestra pit & curtain up)	Ballet	Opera	Passive (forestage & curtain down)	Symphony	[illegible]
RT30 (s)	125	1.62	1.76	1.61	1.70	1.78	1.30	2.16	2.38
	250	1.41	1.52	1.41	1.56	1.56	1.15	2.13	2.20
	500	1.14	1.28	1.18	1.48	1.43	1.05	1.94	2.16
	1000	1.02	1.13	1.10	1.46	1.37	1.02	1.75	1.96
	2000	0.97	1.03	1.06	1.34	1.26	0.97	1.72	1.84
	4000	0.91	0.97	1.00	1.27	1.19	0.92	1.65	1.78
EDT (s)	125	1.43	1.59	1.38	1.45	1.57	1.13	1.91	2.14
	250	1.07	1.19	1.15	1.48	1.36	1.07	1.99	2.01
	500	0.98	1.02	1.06	1.40	1.34	1.07	1.88	2.00
	1000	0.95	1.00	1.02	1.45	1.33	1.03	1.74	1.88
	2000	0.83	0.90	0.95	1.36	1.19	0.82	1.66	1.75
	4000	0.81	0.86	0.88	1.22	1.11	0.77	1.59	1.68
C80 (dB)	125	1.60	0.78	0.50	-1.32	-0.87	2.73	-0.63	-0.71
	250	4.05	3.26	2.09	-0.97	0.60	3.73	-1.44	-1.08
	500	5.27	4.74	3.35	-0.61	1.43	4.55	0.27	0.01
	1000	7.00	6.23	4.24	-0.28	2.03	6.20	1.72	1.27
	2000	8.35	7.50	5.27	0.57	3.24	8.54	3.14	2.80
	4000	8.09	7.13	5.69	1.86	3.82	8.45	3.27	2.91
ΔSPL (dB)	125	x	1.30	x	0.96	1.25	x	2.10	2.32
	250	x	0.60	x	1.44	1.43	x	3.09	3.11
	500	x	1.19	x	2.18	1.74	x	2.39	2.74
	1000	x	0.76	x	2.39	1.65	x	1.91	2.33
	2000	x	0.46	x	1.97	1.31	x	2.00	2.34
	4000	x	0.53	x	1.60	1.18	x	1.94	2.20
Mean JLFC (-)		0.19	0.23	0.24	0.32	0.28	0.18	0.22	0.23

Table 3: Measured values of acoustic parameters in octave band (average of all measures), for each CARMEN® preset. Lateral Early Energy Fraction (JLFC) values are mean values over the whole frequency range for each preset.

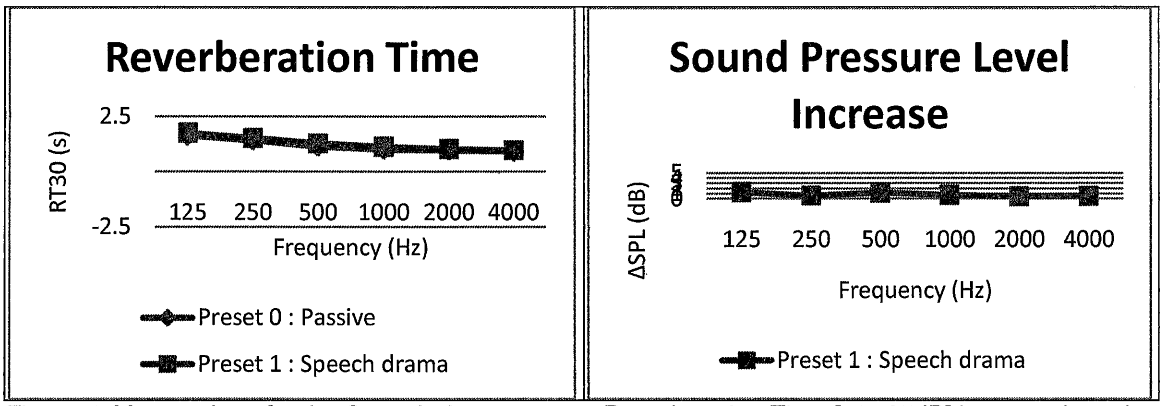

Figure 5: Mean values for the Speech drama preset: Reverberation Time [-5, -35dB] in seconds and SPL increase in dB.

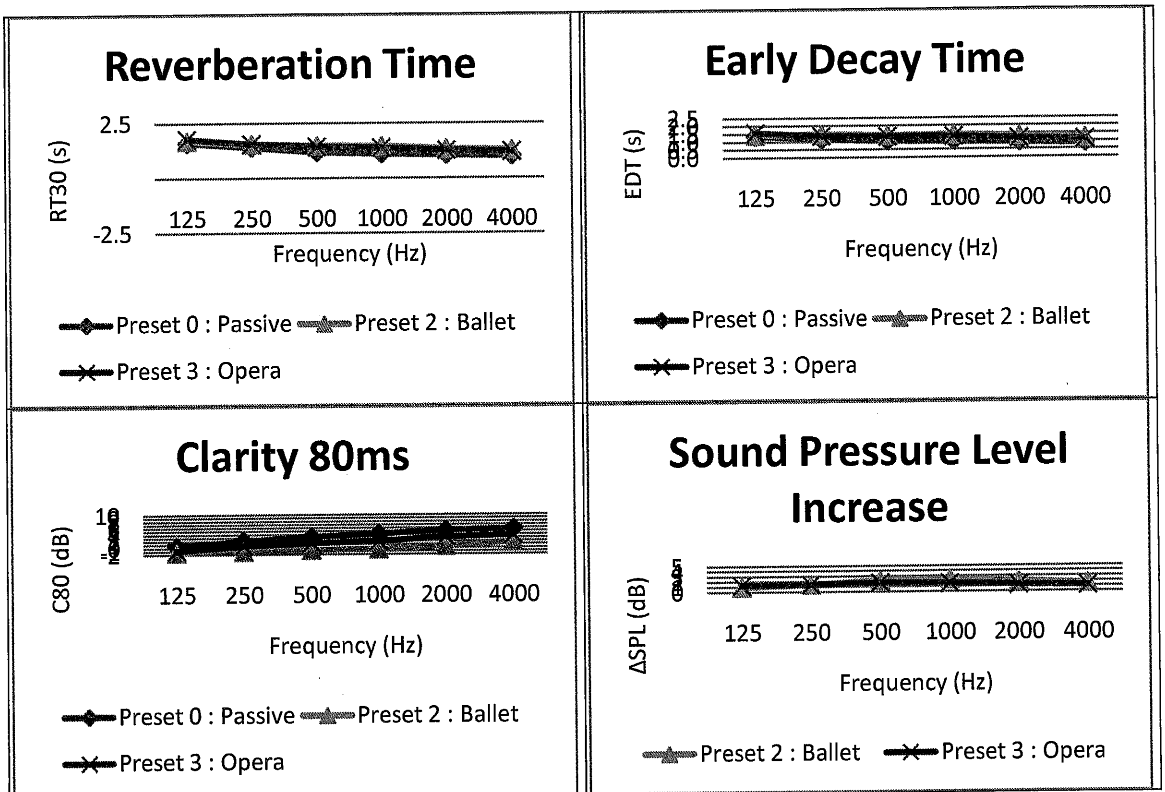

Figure 6: Mean values for the Ballet and Opera presets: Reverberation Time [-5, -35dB] in seconds, Early Decay Time [0, -10dB] in seconds, Clarity 80 ms in dB and SPL increase in dB.

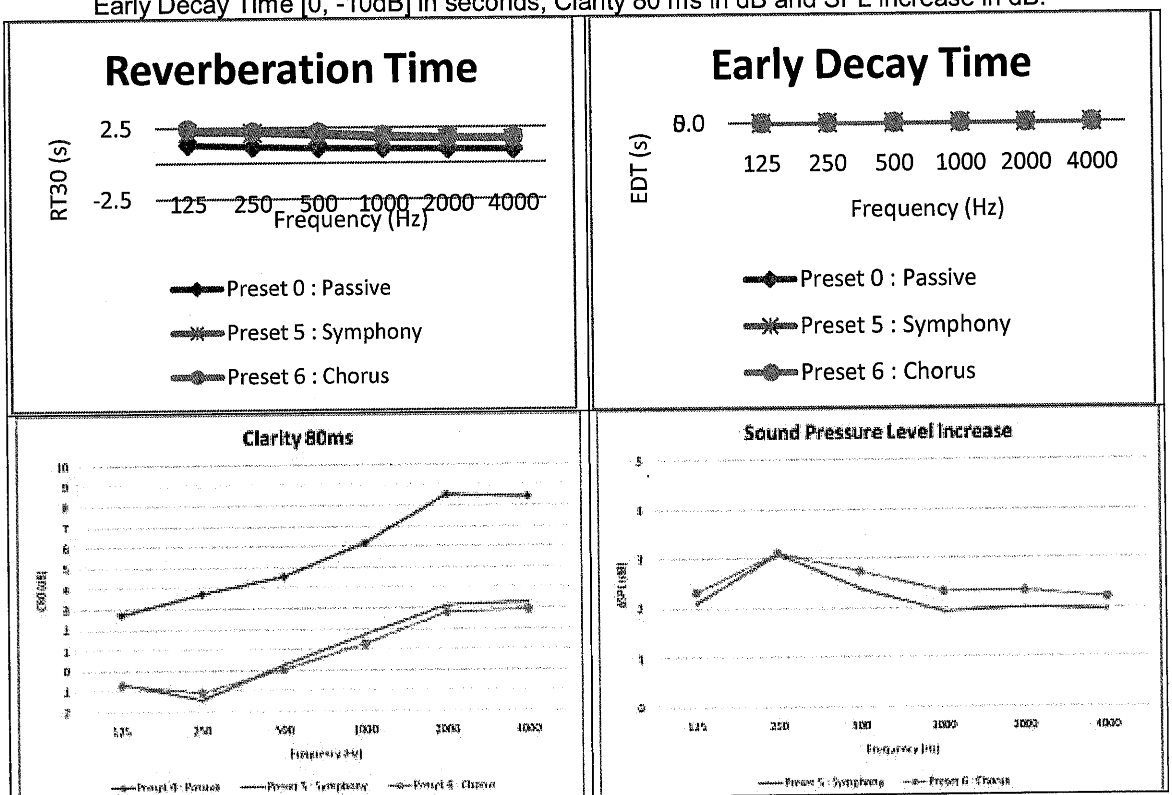

Figure 7: Mean values for the Symphony and Chorus presets: Reverberation Time [-5, -35dB] in seconds, Early Decay Time [0, -10dB] in seconds, Clarity 80 ms in dB and SPL increase in dB.

It should be noted that high values of musical clarity and lateral energy have been achieved as well as the increases in reverberance. Values for clarity are lower for the Ballet setting (but still within the brief), reflecting the fact that not all seats have a direct line of sight to the pit.

The results of Sound Level distribution in dB(A) for the 11 measurement positions with and without the CARMEN® system are shown in Figure 8. These measurements have been obtained with a Bruel & Kjaer 2230 sound level meter in LAeq mode and are relative to the sound power of the measurement source. Results have been grouped in 4 categories corresponding to the 3 different auditorium and stage set-ups and the 2 different positions of the measurement source:

- Fire curtain opened, with orchestra pit, source in the orchestra pit (Ballet and Opera preset).
- Fire curtain closed, with forestage up, source on forestage (Symphony and Chorus preset).

It is important that the overall sound level increase is minimal, in order that the enhancement system sounds natural rather than amplified. This is shown well in the figures, with the maximum increase being only 3 dB(A).

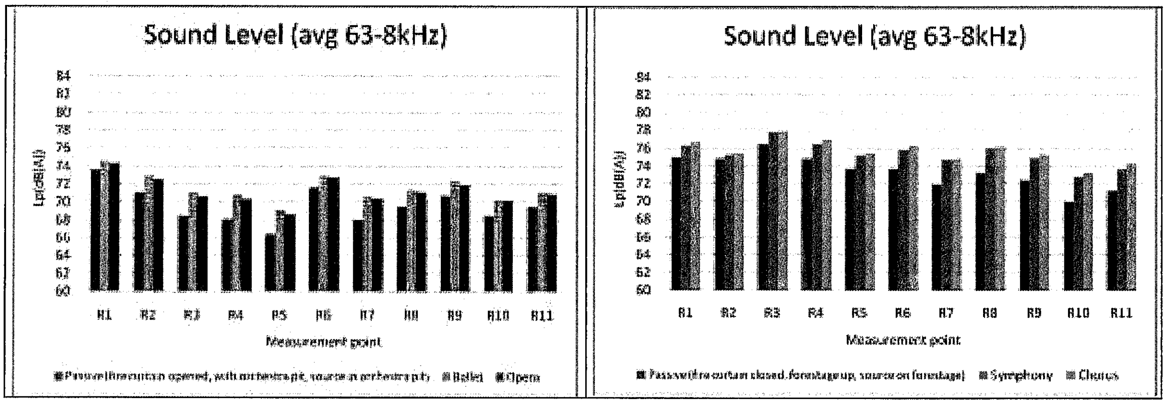

Figure 8: Sound Level in dB(A) for the 11 measurement positions and the different presets.

9 CONCLUSION

The successful design and installation of the CARMEN® electroacoustic enhancement system in the Aylesbury theatre proves the possibility of achieving good acoustics for each use in a multi-purpose theatre. The enhancement system is the most cost effective means to provide a variable acoustic in this venue. It has enabled savings to be made on the building cost and provides the optimum natural acoustic for the majority of events. Considerable savings are also made in the operational costs of the theatre, changing between different acoustic states at the flick of a switch.

10 REFERENCES

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