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Acoustic Characterization of the Theatre Diogo Bernardes (Ponte de Lima)

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Abstract

This paper provides an acoustic characterization of the Theater Diogo Bernardes (Ponte de Lima, Portugal). The main results of the measured acoustic parameters were: LAeq(HVAC) at 26 dB, Speech Transmission Index ranging from 0.56 to 0.71, Reverberation Time (avg 500-1k Hz) of 0.99 s, C_{80} (avg 500-1k Hz) of 4.7 dB, D_{50} avg 500-1k Hz) of 0.59, and Center Time (avg 500-1k Hz) of 63 ms. A comparison is made with 19 Portuguese halls and five international horseshoe-type theaters.

Keywords: *acoustics, theater, reverberation, intelligibility.*

1. Introduction

The goal of this study is to analyze the acoustics of the Diogo Bernardes Theatre (DB) (Fig. 1 and 2) inaugurated in 1896 and fully rehabilitated in 1999, through on-site measurements of various acoustic parameters and to evaluate whether the space is suitable for its intended purpose as a performance venue, ensuring compliance with Portuguese laws and recommended reference values for this type of venue. Comparison is made with other venues with similar architectural characteristics, enabling the theatre's acoustic performance to be assessed against national and international benchmarks.

Figure 1. Interior of the Diogo Bernardes Theatre.

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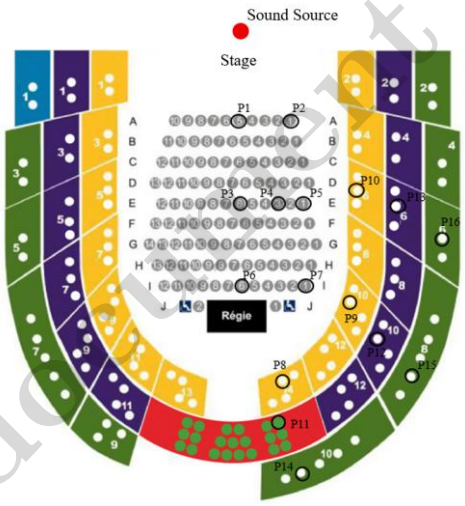

Figure 2. Floor plan of the Theatre Diogo Bernardes showing the auditorium layout and the locations of the acoustic measurement positions.

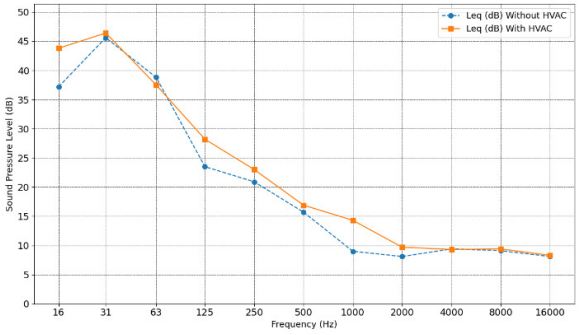

Figure 3. Comparison of the average background noise sound pressure levels, in 1/1-octave frequency bands, with and without the HVAC on, at Theatre Diogo Bernardes.

2. Results

2.1 Background noise

2.1.1 On-site measurements

Analysis of Figure 3 allows us to assess the impact of the HVAC system's operation on background noise levels in the room. SPL values without the HVAC system range from 8.1 to 45.6 dB, while with the HVAC system on, they increase to 8.3–46.4 dB. The difference between the two system states shows greater noise at low frequencies, particularly at 16 Hz

(6.6 dB) and 1 kHz (5.2 dB). Overall, LAeq increased by 1.9 dB with the HVAC switched on, whilst Leq increaees by 3.9 dB. These results demonstrate that the HVAC system contributes to a moderate increase in background noise but should not compromise speech intelligibility or the sound experience.

2.1.2 NC and NR curves

The assessment of background noise in the hall was supplemented by the determination of the NC (Noise Criteria) and NR (Noise Rating) curves (Table 1). These indicators allow the measured levels to be compared with the recommended maximum values for theatres and concert halls, generally situated between 20 and 30, which are considered adequate to ensure clear speech and music perception. Analysis of the results in Table 1 indicates that, with the HVAC system both on and off, the value remains below the recommended limits. The influence of the HVAC system's operation proves to be minimal, with a variation of 0 for the NC curves and 1 for the NR curves. It can therefore be concluded that the Theatre Diogo Bernardes offers adequate acoustic comfort conditions regarding background noise, ensuring levels are compatible with the staging of performances and musical activities, even with the HVAC system in operation.

Table 1. Calculated values for NC and NR based on the operation of the HVAC system and its variation, compared with the recommended maximum values.

	NC	NR	Recommended maximum levels (Theatre and music)
With HVAC	15	17	20 a 30
Without HVAC	15	16	20 a 30
Variation (Δ with HVAC)	0	1	

Table 2. Regulatory assessment (RRAE) of the equivalent continuous sound level at the Diogo Bernardes Theatre.

Usage	Mesurement	L_{Aeq} (dB)	Uncertainty factor dB(A)	L_{Aeq} with uncertainty factor (I) (dB)	RRAE L_{Aeq} (dB)	Verification
Venues (excluding cinemas)	With HVAC	26	3	23	≤ 30	OK
	Without HVAC	24		21		
Cinemas	With HVAC	26	3	23	≤ 38	OK
	Without HVAC	24		21		

2.1.3 Compliance with Portuguese legislation

Verification of compliance with background noise levels under the Portuguese Building Acoustic Requirements Regulation (RRAE) was based on L_{Aeq} values obtained with the HVAC system switched on and off. To ensure a conservative analysis, an uncertainty factor of 3 dB(A) was applied, as required by the regulation, by subtracting it from the measured values. Thus, the levels considered for verification were 23 dB(A) with the HVAC system running and 21 dB(A) with the system switched off. These values were compared with the limits established by the RRAE for performance venues, which set a maximum value of 30 dB(A) (and 38 dB(A) for cinemas).

Table 2 shows that both situations meet regulatory requirements, with compliance with the RRAE confirmed whether the HVAC is on or off. The system's operation introduces only a 2 dB(A) increase in background noise, without compromising the room's overall acoustic quality.

2.2 Reverberation Time

2.2.1 On-site measurements

The RT values in Figure 4 were analyzed across the frequency range 125-4k Hz, including the calculation of the mean values for 500 and 1k Hz and their respective standard deviations. Analysis of the results reveals relatively small differences between the various measurement points. The overall mean value obtained for RT [500,1k Hz] was 0.99 s, with a standard deviation of 0.09 s. Although some differences exceed the threshold for the minimum perceptible differences (≈5%), particularly in certain frequency bands and at extreme points, these variations do not indicate significant acoustic irregularities.

It can therefore be concluded that the overall reverberation time behavior exhibits a relatively homogeneous distribution within the analyzed space, with the observed variations being consistent with the unoccupied room condition at the Theatre Diogo Bernardes.

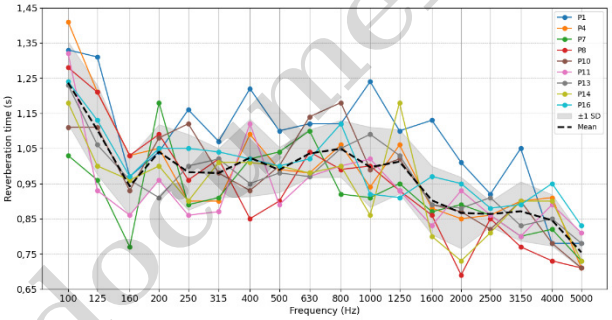

Figure 4. Reverberation time values for the measurement points in 1/3-octave frequency bands, at the Theatre Diogo Bernardes.

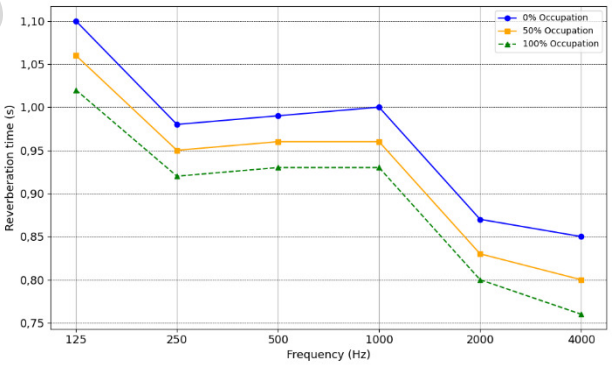

Figure 5. Estimated Reverberation Time values with room occupancy rates of 0%, 50%, and 100%, in 1/1-octave bands.

2.2.2 Forecast for a fully occupied room

To evaluate the room's acoustic behavior under real-world conditions, the variation in RT values with occupancy was analyzed. The estimate was based on the difference in sound absorption between occupied and unoccupied seats [1], considering three occupancy levels: 0%, 50%, and 100% (Figure 5). The seating area was determined from the seats' area, including, wherever possible, an additional 0.5 m strip around their perimeter. Using the room volume (2,590 m³) and Sabine's formula, RT values were estimated for each occupancy scenario. This approach, which uses Sabine's

formula to simplify calculations, constitutes a preliminary analysis of the room's acoustic behavior under different occupancy conditions.
The results show that the estimated RTs at 50% and 100% occupancy decrease only slightly, changing by less than 0.06 seconds compared with the empty-room scenario. This small difference suggests that the space already has significant sound absorption, due to the upholstered chairs and the surrounding environment.

2.2.3 Compliance with Portuguese legislation

According to the Portuguese Regulation on Acoustic Requirements for Buildings (RRAE), Table 3, the maximum permissible RT is determined as the average of the 0.5, 1, and 2 kHz frequency bands, with the limit set by the room volume. In the case of auditoriums and rooms intended for 'speech' use, the limit value is given by the expression 0.32+0.17log V. The regulation also requires applying a 35% uncertainty factor to the measured average value. Taking this correction into account, a regulatory RT of 0.63 s was obtained, a value which is below the permissible limit of 0.90 s. Therefore, it can be concluded that the DB Theatre meets RRAE's standards for RT.

Table 3. Regulatory analysis (RRAE) of the average reverberation time with the HVAC system off at the Diogo Bernardes Theatre.

	Frequencies in 1/1 octave bands (Hz)	Measured TR (s)	Average TR (s)	Maximum TR RRAE (s)	Uncertainty factor (I)	Average TR with uncertainty factor (I) (s)	Assessment for "public speaking" (RRAE)
Without AVAC	500	0,99	0,95	**0,90**	35%	**0,63**	**O.K.**
	1k	1,00					
	2k	0,87					

Table 4. Verification of the recommended values for the average Reverberation Time parameter in accordance [2, 3].

Function	TR [500, 1 kHz] ideal (s)	TR [500,1k Hz] (s)	Evaluation
Auditorium (noun)	0,7 a 0,8	**0,93**	**Acceptable**
Theatre	0,7 a 0,9		**Suitable**
Cinema	0,8 a 1,0		**Suitable**
Opera (not Wagnerian)	1,3 a 1,7		**Inappropriate**
Opera (Wagnerian)	1,8 a 1,9		**Inappropriate**
Baroque symphonic music	1,4 a 1,6		**Inappropriate**
Classical symphonic music	1,6 a 1,8		**Inappropriate**
Romantic symphonic music	1,9 a 2,2		**Inappropriate**
Modern symphonic music	1,4 a 1,9		**Inappropriate**
Popular music	0,8 a 1,0		**Suitable**
Organ music	2,5 a 3,5		**Inappropriate**
Gregorian chants	3 a 4		**Inappropriate**

2.2.4 Assessment based on ideal values

The acoustic suitability of the hall was evaluated by comparing measured RT values with recommended ideal values for different types of use (Table 4) to determine if the space adequately meets the acoustic requirements for each activity.
Considering an average (500, 1k Hz) RT of 0.93 s for 100% occupancy, the DB Theatre offers suitable conditions for functions such as theatre, cinema, and popular music. Conversely, it is less suitable for activities that require longer reverberation times, such as symphonic music, opera, or choral repertoire. Overall, the auditorium offers satisfactory acoustic performance for certain uses, although it is not ideal for all the functions analyzed.

2.3 Speech Transmission Index (STI)

Analysis of the Speech Transmission Index (STI) enasbles an objective assessment of speech intelligibility, ranging from 0 (worst-case) to 1 (best-case). The results indicate that, overall, the room exhibit intelligibility levels between "Sufficient" and "Good" when the HVAC system is off and in operation (Figure 6).
The average STI value was 0.62 in both conditions, at the lower limit of the "Good" category. The low standard deviation (0.04) indicates a relatively homogeneous distribution of speech intelligibility throughout the room, with no significant differences among measurement points. A comparison of measurements with and without the HVAC system shows that the system's operation has no significant effect on speech intelligibility. The recorded variations (not exceeding 0.02) are below the minimum perceptible difference (0.05), indicating that the HVAC system's background noise does not perceptibly affect speech intelligibility.
Overall, the DB Theatre performs well in terms of speech intelligibility, with no critical areas and acoustic characteristics suitable for events requiring good speech perception.

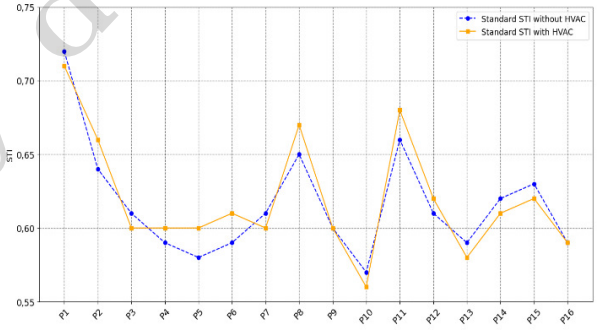

Figure 6. Comparison of average STI values for points P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15 and P16 with and without HVAC at the Diogo Bernardes Theatre.

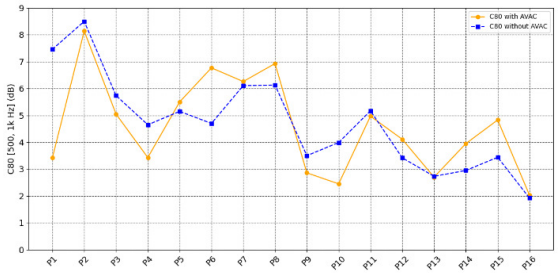

Figure 7. Comparison of the average values of the C80 [500–1k Hz] clarity parameter (dB) at the measurement points at the Diogo Bernardes Theatre, with and without the HVAC system.

2.4 Clarity (C_{80})

Clarity (C_{80}) expresses the ratio between the initial sound energy (first 80 ms) and the late energy, serving as an indicator of sound definition. At the DB Theatre, the average

C_{80} values obtained without HVAC range from 6.1 dB (125 Hz) to 8.9 dB (8 kHz), with 4.7 dB in the [500, 1k Hz] bands, indicating good sound definition. With the HVAC on, the values differ by less than 1 dB, confirming that the system does not significantly impact Clarity. The spatial distribution remained consistent, with no acoustically problematic areas (Figure 7).

It is concluded that the auditorium provides clear sound quality, suitable for the standard acoustic needs of a medium-sized theater.

An analysis of Table 5 shows that the DB Theatre has tolerable C_{80} [500–1k Hz] values for speech, theatre, cinema, and popular music, though slightly below ideal values. In contrast, for musical genres such as Wagnerian opera, symphonic music (Baroque, Classical, Romantic, and Modern), organ music, and Gregorian chants, the measured values are insufficient because they are too high and do not meet the recommended levels. The presence of HVAC does not affect this assessment, indicating that the acoustic performance in this room stays virtually the same between the two conditions.

Table 5. Assessment of the ideal values for the Clarity (C_{80}) parameter based on the intended use of the space for the Diogo Bernardo Theatre.

Function	C80 [500.1 kHz] ideal (dB)	C80 [500, 1 kHz] measured (dB)		Evaluation
		With AVAC	Without AVAC	
Auditorium (noun)	> 6	4,6	4,7	Acceptable
Theatre	> 6			Acceptable
Cinema	> 5			Acceptable
Opera (not Wagnerian)	3 a 4			Acceptable
Opera (Wagnerian)	1 a 2			Inappropriate
Baroque symphonic music	0 a 2			Inappropriate
Classical symphonic music	-1 a 0			Inappropriate
Romantic symphonic music	-2 a -1			Inappropriate
Modern symphonic music	-1 a 0			Inappropriate
Popular music	> 6			Acceptable
Organ music	< -2			Completely inappropriate
Gregorian chants	-3 a -1			Inappropriate

2.5 Definition (D_{50})

The influence of the HVAC system on the D_{50} [500, 1k Hz] was evaluated by comparing measured values with and without the system operating (Figure 8). Overall, the average decreased from 0.59 (without HVAC) to 0.58 (with HVAC), indicating no significant statistical difference, as expected.

Point-by-point analysis, however, reveals more significant local differences. Point 1 (front row) had the largest decrease (ΔD_{50} = 0.21), while Point 6 showed the largest improvement (ΔD_{50} = −0.12). Minor changes (ΔD50 < 0.05) occurred at other points, and some areas, such as Point 16 (box seat), remain with low values regardless of HVAC, indicating that structural and geometric limitations are the main factors. In summary, HVAC does not significantly alter the typical room definition, although it can affect specific locations locally.

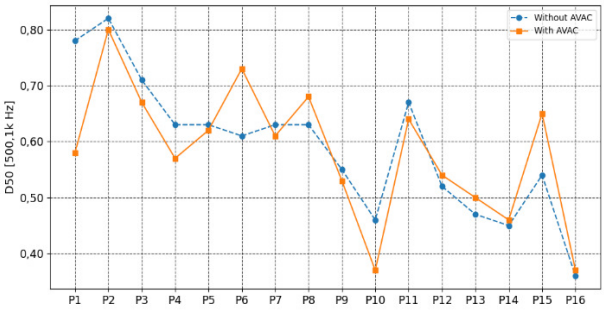

Figure 8. Comparison of the mean values of D_{50} for measurement points with and without the HVAC system at the Diogo Bernardes Theatre.

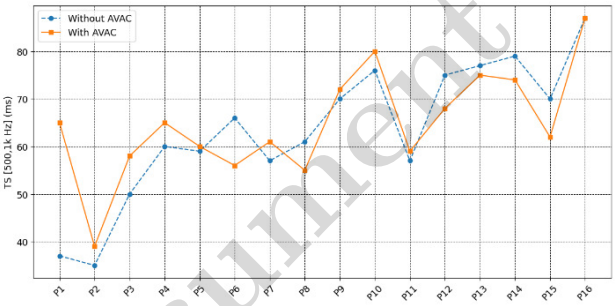

Figure 9. Comparison of the average values for the Central Time (TS) parameter [500, 1k Hz] (ms) for the measured points with and without the HVAC system at the Diogo Bernardes Theatre.

2.6 Central Time (TS)

The influence of the HVAC system on Central Time (TS) was assessed at frequency bands of 500 and 1k Hz. The overall average TS is slightly higher with HVAC (65 ms) compared to without HVAC (63 ms), indicating a generally insignificant effect (Figure 9).

Point-by-point analysis reveals significant local variations. Point 1 (front row) shows a marked increase from 37 ms to 65 ms, suggesting that the HVAC system introduces additional reflections or diffusion that may affect speech intelligibility in this area. Other points, such as P6, P8, and P15, show slight increases of 6 to 10 ms, indicating that the HVAC system's effect depends on the geometry and relative position within the system.

The standard deviation of the values (13 and 15 ms) and the average ΔTS of 5 ms confirm that, overall, the HVAC system does not affect the sound's temporal behavior. However, isolated points may show perceptible changes, indicating that the system's influence is not uniform throughout the hall.

Table 6. Verification of the recommended values for the 'Average Central Time' parameter in accordance with the operating and non-operating modes of the HVAC system at the Diogo Bernardes Theatre.

Function	TS [500, 1 kHz] ideal (ms)	TS [500, 1 kHz] measured (ms)		Evaluation
		With AVAC	Without AVAC	
Music	80 a 230	65	63	Inappropriate
Word	< 80			Appropriate

An analysis of Table 6 compares the measured average Central Time (TS) values with the recommended ranges for various functions. For the music function, the ideal TS values [500–1k Hz] lie between 80 and 230 ms. The measured results, both with HVAC at 65 ms and without AVAC at 63 ms, fall below the recommended range and are therefore classified as inadequate. This result indicates that the room does not provide the necessary temporal sustain for musical reproduction, particularly for pieces with complex or prolonged harmonic content. On the other hand, for speech, the ideal RT should be less than 80 ms, a value consistent with results measured in the room. With HVAC, the average RT is 65 ms, and without AVAC, it is 63 ms, both within the recommended limit and therefore considered adequate. This adequacy shows that the room provides good speech clarity.

Table 7. Effect of the HVAC system's operation on the acoustic parameters measured at the Diogo Bernardes Theatre.

Parameters		Effect of HVAC
Reverberation time (s) [500, 1 kHz]		≈ 0
Clarity (C_{80}) (dB) [500,1k Hz]		+ 0,14
Definition (D_{50}) [500,1k Hz]		≈ 0
Central Time (TS) (ms) [500,1k Hz]		-2
Discomfort curves	NC (*Noise Criterion*)	0
	NR (*Noise Rating*)	+1
Equivalent sound level (L_{Aeq}) (dB)		+2
Equivalent sound pressure level (L_{eq}) (dB)		+4
Speech Transmission Index (STI)		≈ 0
Ratio of Basses		≈ 0

2.7 Assessment of the impact of HVAC

The integrated assessment of acoustic parameters with the HVAC system, both on and off, enables analysis of how the system influences the room's performance (Table 7). Generally, it was found that the HVAC system does not significantly change the fundamental sound quality parameters C_{80}, D_{50}, Central Time (TS), Bass Ratio, and Speech Transmission Index (STI), with variations staying below the smallest perceptible differences. Therefore, speech intelligibility and music reproduction are not affected.

The most significant impact of the HVAC system is on background noise, with an increase of approximately +2 dB in L_{Aeq} and +4 dB in L_{eq}, concentrated in the low frequencies. NC and NR show an almost unchanged situation of just +1 dB, remaining within acceptable levels for theatrical and musical performances. In summary, the HVAC system at the DB Theatre meets the requirements of the RRAE, without introducing any perceptible changes to the essential acoustic parameters.

3. Comparative Analysis with other Rooms

3.1 International rooms in Horseshoe

Table 8 presents a comparison between the DB Theatre and five international venues with a 'horseshoe' layout, considering RT values measured under consistent conditions (i.e., unoccupied venues).

The results show that the DB Theatre has an average RT of 0.99 s [500–1k Hz], placing it above the trend observed in the relationships between RT and volume and between RT and number of seats. In contrast, larger venues, such as the Paris Opera Garnier (1.22 s), the Milan Teatro alla Scala (1.36 s), and the London Royal Opera House (1.21 s), exhibit longer RT values consistent with their greater volume.

Despite its small size, the DB Theater shows a relatively moderate RT average given its capacity and volume. This feature may affect speech clarity and overall sound quality perception at some events.

Table 8. Average reverberation time values (RT [500, 1k Hz]), unoccupied, for five international 'horseshoe'-shaped auditoriums and the Diogo Bernardes Theatre, with their respective volumes and number of seats (+, -: highest and lowest values in each column) [1].

Theatres	N° of seats	Volume (m3)	TR(s) [500, 1 kHz] Unoccupied
Theatre Royal, Bristol	638	2170 (-)	0,80 (-)
Opera Garnier, Paris	2131	10000	1,22
Teatro alla Scala, Milão	2289	11252	1,36
Royal Opera House, Londres	2120	12250	1,21
Usher Hall, Edimburgo	2550 (+)	16000 (+)	1,70 (+)
Theatre Diogo Bernardes, Ponte de Lima	245 (-)	2590	0,99

Table 9. Capacity, number of seats, capacity per seat, and average TR (500, 1k Hz) for the 19 national theatres and the Diogo Bernardes Theatre (+, -: highest and lowest values in each column) [2].

Reverberation time (s)				
Venues	Volume (m^3)	Number of seats	Volume/ Nº Lugares (m^3)	TR [500, 1 kHz] (s)
FEUP Auditorium	3317	500	6,6	1,5 (+)
V. N. de Gaia Municipal Auditorium	3219	330	9,8	0,8
Ílhavo Cultural Centre	3779	491	7,7	1,0
Águeda Arts Centre	5066	398	12,7	0,8
Amarante Cinema Theatre	2700	386	7,0	1,2
Eduardo Brazão Cinema and Theatre (Valadares)	2111	386	5,5	1,0
Main Auditorium at Altice Forum Braga	9150	998	9,2	1,0
Main Auditorium of the Convent of St Francis (Coimbra)	12000 (+)	1093 (+)	11,0	1,5 (+)
Small Auditorium at Altice Forum Braga	1320 (-)	254	5,2 (-)	0,5 (-)
Covilhã Municipal Theatre	4258	600	7,1	1,4
Ourém Municipal Theatre	3915	441	8,9	1,0
Auditorium of the Porto Conservatory of Music	3162	233 (-)	13,7 (+)	1,3
Jordão Theatre (Guimarães)	2230	386	7,8	0,70
Garrett Cinema and Theatre (Póvoa de Varzim)	5320	471	11,3	1,0
Carlos Alberto Theatre (Porto)	3315	250	13,3	1.2
Sá de Miranda Theatre (Viana do Castelo)	2491	377	6,6	1.2
São João National Theatre (Porto)	4560	614	7,4	1,2
Ribeiro Conceição Theatre (Lamego)	4184	417	10,0	1,1
Theatro Circo (Braga)	9800	897	10,9	1,2
Diogo Bernardes Theatre (Ponte de Lima)	**2590**	**245**	**10,6**	**1,0**

3.2 National Theatres of all sizes/shapes

3.2.1 Reverberation Time (RT)

A study of 20 national theaters of varying sizes shows that RT values generally rise with volume and the volume-to-seating-capacity ratio. The DB theatre, with an average RT

of 1.0 s and an auditorium volume of 2,590 m³ lies close to the median of the group, demonstrating a balanced acoustic response for its small size. This positioning indicates that, despite its small volume, the auditorium maintains sufficient reverberation to enhance speech intelligibility without compromising sound quality.
Furthermore, the 10.6 m³ per seat ratio ensures acoustic behavior consistent with its function, comparable to that of larger auditoriums yet adapted to its limited capacity. This combination of volume and seating density makes the DB Theatre especially well-suited for theater and certain types of chamber music performances, providing controlled, uniform, and efficient acoustics that balance clarity, envelopment, and acoustic comfort for the audience.
It is also worth noting that, when examining the relationship among volume, capacity, and RT, the DB Theatre stands out as a good example of the broader trend among Portuguese theatres: it effectively balances the proportions of the space with acoustic quality, showing that even smaller venues can deliver rich, well-defined sound experiences. This characteristic reinforces its versatility, allowing it to be used effectively for different types of performances and cultural contexts.
Tables 9 and 10 present all RT values and other parameters measured across the 20 performance venues studied.

Table 10. Average C_{80}, D_{50}, TS, and RT values (500, 1k Hz) for nine national halls, including the Theatre Diogo Bernardes (+, -: highest and lowest values in each column) [2].

Venues	C_{80} (dB)	D_{50}	TS (ms)	TR (s)
Auditorium of the Porto Conservatory of Music	4,7	0,63	60	1,3 (+)
Jordão Theatre (Guimarães)	8,6 (+)	0,74 (+)	40 (-)	0,7 (-)
Garrett Cinema and Theatre (Póvoa de Varzim)	6,9	0,71	55	1,0
Carlos Alberto Theatre (Porto)	5,7	0,61	63	1,2
Sá de Miranda Theatre (Viana do Castelo)	4,7	0,60	64	1,2
São João National Theatre (Porto)	5,1	0,61	60	1,2
Ribeiro Conceição Theatre (Lamego)	5,6	0,65	58	1,1
Theatro Circo (Braga)	3,6 (-)	0,56 (-)	76 (+)	1,2
Diogo Bernardes Theatre (Ponte de Lima)	**4,7**	**0,59**	**63**	**1,0**

3.2.2 Speech Transmission Index (STI)

An analysis of 20 halls nationwide shows that acoustic performance depends heavily on volume, capacity, and background noise levels. The Speech Transmission Index (STI/raSTI) typically ranges from 0.6 to 0.7, corresponding to good speech intelligibility, with an average of 0.64. A clear trend shows that smaller venues tend to have higher STI values, such as the Small Auditorium at Altice Forum (Braga) (0.80), while larger venues, such as the Theatro Circo (Braga) or the Grand Auditorium at the Convent of São Francisco (Coimbra), show lower yet acceptable values. This pattern confirms the impact of volume on speech perception, indicating that compact spaces can be more effective for spoken-word events.
Background noise is another important factor. When the HVAC system is off, average LAeq levels remain low (26 dB), which is ideal for spoken-word performances. With the HVAC system on, some areas see increases of up to 40 dB, but this rise doesn't always correspondingly lower the STI, indicating that speech intelligibility mainly depends on the natural acoustic qualities of each room. In this context, the DB Theatre has an average STI of 0.62, in line with the overall average, standing out for its low background noise level even with the HVAC on, confirming favorable conditions for spoken-word performances.
The relationship between average RT and STI shows that excessive reverberation compromises speech intelligibility. Venues such as the Small Auditorium at Altice Forum Braga, with an average RT of just 0.5 s, have high STI values, whereas theaters with average RTs exceeding 1.2 s, such as the Sá de Miranda Theatre and the São João Theatre, record lower values, indicating that other factors, such as geometry and the distribution of early reflections, also influence acoustic performance. The DB Theatre is near the average curve, balancing reverberation, sound clarity, and intelligibility.
The impact of background noise reinforces these conclusions. Halls with lower L_{Aeq} levels, such as the DB Theatre and the Ílhavo Cultural Centre (24–26 dB), manage to maintain high STI avg. values (0.62 and 0.68, respectively), whilst the São João National Theatre, with an L_{Aeq} of 31 dB, has a lower avg. STI (0.55). Although there is a correlation between noise level and STI, the coefficient of determination (R^2 = 0.16) indicates that noise level alone does not fully explain the differences in speech intelligibility, highlighting the need for an integrated approach that simultaneously considers reverberation control, room geometry, and the distribution of early reflections to optimize speech perception.

4. Conclusions

Overall, the DB Theatre offers balanced acoustics, ensuring clear speech intelligibility and high sound quality, making it suitable for a wide range of events. However, it is not ideal for certain types of symphonic music due to the required reverberation.
Background noise levels at the DB Theatre are about 25 dB(A), below the RRAE maximum of 30 dB(A), indicating minimal impact from the HVAC system. NC and NR curves around 16 indicate a comfortable acoustic environment, regardless of whether the HVAC is operating. The average RT500-1k of about 1.0 s is suitable for speech but insufficient for opera and symphonic music. The STI indicates good overall intelligibility, ensuring clear verbal communication in most positions. C80 and D50 values show versatile performance suitable for theater and popular music, but not optimized for symphonic music or highly demanding performances.
The average Center Time (63 ms) and the Bass Ratio (1.05) indicate a well-balanced distribution of sound energy and sufficient bass response. In summary, the hall provides balanced, versatile acoustic performance, offers comfort for the audience and performers, and minimizes HVAC system influence on background noise levels.

References

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