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Original Article

Measurement of Acoustic Parameters of the Multipurpose Alev Alatlı Conference Hall

Akın Oktav[1,2*], Mehmet Şahin[2]
[1]Department of Mechanical Engineering, Alanya Alaaddin Keykubat University, Antalya, Türkiye.
[2]Vibration and Acoustics Laboratory, Alanya Alaaddin Keykubat University, Antalya, Türkiye
**akin.oktav@alanya.edu.tr*

Abstract

Multi-purpose halls are used for a wide range of activities, from conferences to concerts, theatre performances to sporting events. The acoustic performance of such halls can vary greatly depending on the type of event, temperature variations, and occupancy of the hall. Therefore, determining the acoustic characteristics of a multi-purpose hall is critical to ensure that the venue can provide the best acoustic performance in every usage scenario. A measurement survey is conducted in a multipurpose conference hall through 2 different stimuli and at 2 different temperatures. The response of the hall is recorded at 10 receiver locations using omnidirectional microphones and a dummy head. The reverberation time, early decay time, bass ratio, center time, clarity, definition, rapid speech transmission index, and inter aural cross-correlation are extracted from the raw data. The results are compared to the relevant standards and the literature to evaluate the acoustic performance.

Keywords: Multipurpose hall acoustics, room acoustic parameters, room impulse response, acoustical performance.

Çok Amaçlı Alev Alatlı Konferans Salonunun Akustik Parametrelerinin Ölçülmesi

Özet

Çok amaçlı salonlar, konferanslardan konserlere, tiyatro gösterilerinden spor etkinliklerine kadar çok çeşitli etkinlikler için kullanılmaktadır. Bu tür salonların akustik performansı, etkinliğin türüne, sıcaklık değişimlerine ve salonun doluluk oranına bağlı olarak büyük ölçüde değişebilir. Bu nedenle, çok amaçlı bir salonun akustik özelliklerinin belirlenmesi, mekânın her kullanım senaryosunda en iyi akustik performansı sağlayabilmesini sağlamak için kritik öneme sahiptir. Çok amaçlı bir konferans salonunda 2 farklı uyaran ve 2 farklı sıcaklıkta bir ölçüm araştırması gerçekleştirilmiştir. Salonun tepkisi, çok yönlü mikrofonlar ve bir yapay kafa kullanılarak 10 alıcı konumunda kaydedilmiştir. Ham veri işlenerek yankılanma süresi, erken sönümlenme süresi, bas oranı, merkez süresi, netlik, tanımlama, hızlı konuşma iletim indeksi ve işitsel çapraz korelasyon elde edilmiştir. Akustik performansı değerlendirmek için sonuçlar ilgili standartlar ve literatürle karşılaştırılmıştır.

Anahtar Kelimeler: Çok amaçlı salon akustiği, oda akustik parametreleri, oda dürtü yanıtı, akustik performans.

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1. INTRODUCTION

The acoustic requirements of the spaces are different, and these requirements are determined according to the intended use. If a space is to be designed as a theatre hall, the targeted room acoustic parameters will be different, for example, if the same space is used as a concert hall, the result may not satisfy the audience. Nevertheless, there is a demand for the same space to be used for different purposes. In this case, it may be preferable to compromise on the ideal values for each requirement, not to have ideal acoustic properties for any event, but still to be able to meet all requirements to some extent. Another way to meet this demand is to use movable panels, directional diffusers, and sound curtains and to adjust these components according to the types of activities. According to Holden [1], this demand dates to the 1920s.

Single-purpose halls are rare due to their high construction costs and operational expenses. Nevertheless, people want to organize a large number and variety of activities and come together. For example, in universities, different activities are constantly organized for students to develop and have a good time. In addition, events such as commemorations and celebrations take place frequently. These events are usually organized in conference halls. In these organizations, speeches are given from the lectern, and from time to time there are also trio and quartet concerts. In some activities, solo and choral singing can be performed. In addition, presentations can be made on the screen and sound recordings can be played. All these activities point to the need to pay attention to more parameters than the intelligibility of the speech for the acoustic performance of the space.

In this study, a multi-purpose conference hall is considered and the adequacy of its acoustic performance in terms of different activities is investigated. For the research, impulse response was measured with a dodecahedron sound source in the hall, and 2 different types of microphones were used: omnidirectional and dummy head. The impulse responses are usually measured using either Maximum Length Sequence (MLS) or Exponential Sine Sweep (ESS) signals. Both signals were used to measure the objective room acoustic parameters, and the results were compared. Another concern is changes in room temperature during these activities. Although the temperature in the halls is tried to be kept constant with air conditioning systems, the room temperature may increase during the performance due to the presence of the audience. Measurements were made at two different temperatures, 25°C and 30°C, and the changes caused by the temperature difference on the room acoustic parameters were investigated.

2. DATA AND METHODS

2.1 Stimuli

In acoustic measurements, the impulse response (IR) and linear transfer function of the system are characterized. The most used technique for IR measurement is the MLS. The MLS signal is comparable to white noise, which is non-periodic and random in nature. The measurement requires long measurement time averaging to ensure that it accurately estimates its spectrum. It is a pseudo-random noise sequence that can be seen as a long sequence of perfect impulses with a perfect white spectrum. In practice, such a signal consists of a distributed sequence of identical positive and negative pulses of the same amplitude, so that it is symmetric around 0 [2]. The pseudo-random MLS signal has a full frequency spectrum, and the sound of MLS signals is less disturbing compared to the intrusive sound produced by sweep signals. When using this technique, it is assumed that the system behaves linearly and does not change over time. When these assumptions are not fully met, problems may arise in measurements.

It is possible to simultaneously solve the linear IR of the system and separate IRs for each harmonic distortion order by using a sine signal whose frequency varies exponentially. This method, known as exponential sine sweeps (ESS), is recommended because it separates harmonic distortion and gives higher impulse–noise ratios (INR) under usual test conditions [3-5]. Farina [6] showed that by using a sine signal whose frequency varies exponentially, it is possible to simultaneously resolve the linear impulse response of the system and separate impulse responses for each order of harmonic distortion. The use of exponential sine sweep (ESS) for impulse stimulation was adopted in relevant works [7-10].

To compare the MLS and ESS signals, the researchers made measurements in a concert hall [4]. In the 500 Hz octave band, the energy/decay plot of the ESS measurement showed that a longer valid decay interval is needed for RT calculation compared to MLS. They showed that under ideal measurement conditions without any disturbing noise, the differences in the RT calculation from a measurement with MLS and ESS are very small. Antoniadou et al. [5] generated artificial background noise and investigated how this noise changes the acoustic parameters for MLS and ESS measurements. The researchers report that MLS methods give better results for white, narrowband, and tonal high background noise, but in the case of impulsive noise, the ESS method performs well [11].

To evaluate the results in a multipurpose conference hall both stimuli, MLS and ESS are used, and raw data are collected in the current work.

2.2 Effect of the Temperature

Even though the halls are assumed to be linear time invariant (LTI) systems, they are exposed to some dynamic changes which alter their characteristics like room acoustic parameters. Temperature and relative humidity changes are some of these dynamic changes. Temperature and relative humidity are constantly changing in halls, especially during performances, with the presence of the audience and the operation of HVAC systems. As stated in a recent work, these changes alter the reverberation time (RT), and this variation is frequency-dependent [12]. The variance in RT also affects the other acoustic parameters like speech transmission index (STI) and clarity (C80) [13-15]. Recent studies show that RT at high frequencies increases and STI decreases when temperature and humidity increase [16]. It was observed that temperature and relative humidity changes were more effective on C80 and T30 parameters, while D50 and EDT were less affected by these changes.

For comparison, the measurements are repeated in two different temperatures, 25°C and 30°C in the current work.

2.3 Descriptors of Room Acoustics

The following descriptors of room acoustics are extracted from the raw data: reverberation time (RT), early decay time (EDT), bass ratio (BR), center time (Ts), clarity (C80), definition (D50), rapid speech transmission index (RASTI), and inter aural cross-correlation (IACC) [17, 18].

RT is the time required for the sound energy in the space to decrease by 60 dB after the source emission has ceased. This change means a reduction in sound intensity to one part per million (10 log 1,000,000 = 60 dB) or a reduction in sound pressure level to one part per thousand (20 log 1,000,000 = 60 dB).

EDT is the time required for a 10 dB reduction of the field-averaged sound energy after the source emission is stopped. It is multiplied by 6 to make it comparable to RT. The abbreviations RT10 and T10 are also used in the literature for EDT. The EDT is a variable that considers especially the earlier and louder parts of the room acoustics. It is therefore related to the masking threshold of reflections, which partially mask the direct sound, causing ambiguity and incomprehensibility. Also, like the reverberation impression, the EDT can vary between different locations in the room.

BR is defined as the ratio of RT at low frequencies to those at mid frequencies in full auditoriums. It is calculated as the sum of the RT values at 125 and 250 Hz divided by the sum of the RT values at 500 and 1,000 Hz. BR with a value of unity indicates a balance between low and mid frequencies in the response of the space. However, high BR values are not desired for speech intelligibility.

$$BR = \frac{RT_{125} + RT_{250}}{RT_{500} + RT_{1,000}} \tag{1}$$

Ts is defined as the variable that gives the center of gravity of the damped sound field with respect to the time axis. It has an inverse correlation with D50 and C80. Low values mean that the definition and clarity are good. Depending on the type of music, a value range of 70-150 ms is considered ideal. In Equation (2) $g(\tau)$ is impulse response.

$$T_s = \frac{\int_0^\infty \tau g^2(\tau)d\tau}{\int_0^\infty g^2(\tau)d\tau} \quad (2)$$

C80 is defined as the difference between the sound energy in the first 80 ms and the late reverberation energy after the first 80 ms. Used as an indicator of the clarity of music, C80 defines the degree to which the details of simultaneous (vertical) and consecutive (horizontal) sounds can be perceived distinctly. Early reflections are integrated directly into the sound by the auditory system and therefore have an amplifying effect. Reverberation has a masking effect and therefore reduces clarity. Therefore, a compromise between reverberation and clarity is desirable. Since it varies with frequency, it needs to be weighted. For this purpose, the average of the C80 values in the frequency octave bands centred at 500 Hz, 1,000 Hz, and 2,000 Hz is commonly used. This average is expressed by the abbreviation C80(3). Depending on the type of music, a C80 value of -3.2 dB to 0.2 dB is considered ideal.

$$C_{80} = 10\log_{10}\left(\frac{\int_0^{80\text{ms}} g^2(\tau)d\tau}{\int_{80\text{ms}}^\infty g^2(\tau)d\tau}\right) \quad (3)$$

D50 is a measure of how well the vocal is intelligible in a space. It is defined as the ratio of sound energy arriving early (0-50 ms after direct sound arrival) to the total received energy. The values of different frequency bands need to be weighted to obtain a single number. The ISO 3382-1 [19] standard recommends that the single D50 number be obtained from the average of the 500 and 1,000 Hz octave bands. The first acoustic reflections arriving very soon after the direct sound have a positive effect on the audience's ability to recognise the vocal, whereas reflections arriving 50 ms or more after the direct sound have a negative effect.

$$D_{50} = \frac{\int_0^{50ms} g^2(\tau)d\tau}{\int_0^\infty g^2(\tau)d\tau} \leq 1 \quad (4)$$

Spatial information is obtained by utilizing binaural hearing and the differences between the sound heard by the two ears. It is about the perception of the spaciousness of the space i.e., listener envelopment. IACC is the maximum absolute value of the interaural cross-correlation function (IACF), and it is an objective descriptor of the perception of the spaciousness of the space.

$$IACF\ (t) = \frac{\int_{t_{min}}^{t_{max}} g_r(\tau)g_l(\tau+t)d\tau}{\left(\int_{t_{min}}^{t_{max}} g_l^2(\tau)d\tau \int_{t_{min}}^{t_{max}} g_r^2(\tau)d\tau\right)^{1/2}} \quad (5)$$

The impulse responses, $g_{l,}$ and g_r, can be measured through the left and right microphones built into a dummy head. IACC is given as

$$IACC = \max\{|IACF(t)|\} \quad (6)$$

Since the difference between STI and rapid speech transmission index (RASTI) is often small, RASTI is used instead of STI as an objective descriptor of speech intelligibility. RASTI is defined as [20]

$$RASTI = \frac{\text{ave}\{SNR(\Omega)\} + 15\text{dB}}{30\text{dB}} \quad (7)$$

where averaging is done over all modulation frequencies (Ω), and SNR is the signal-to-noise ratio.

2.4 Alev Alatlı Hall

Measurements were made in a multipurpose conference hall located at Alanya Alaaddin Keykubat University. Opened in 2023, the 264-seat hall is used for conferences, trio or quartet concerts, and various events. The length of the hall is 19.80 m, width 15.90 m, average height 3.46 m, and volume 1,077 cubic meters. The dimensions of the space are tabulated in Table 1.

In the hall, the stage floor is covered with parquet, and the rest of the floor is covered with tufted pile carpet. As can be seen in Figure 1, a certain part of the walls and ceiling are covered with fabric and the remaining area is painted plaster surface. The audience seats in the hall are covered with heavily upholstered fabric. The side view of the hall is shown in Figure 2 where the dimensions are also depicted.

Table 1. The dimensions of the hall

Volume (V)	1,077 m^3
Surface area	314.82 m^2
Number of seats (N)	264
Stage area	52.53 m^2
V/N	4.08

Figure 1. Alev Alatlı hall located at Alanya Alaaddin Keykubat University, Antalya, TR

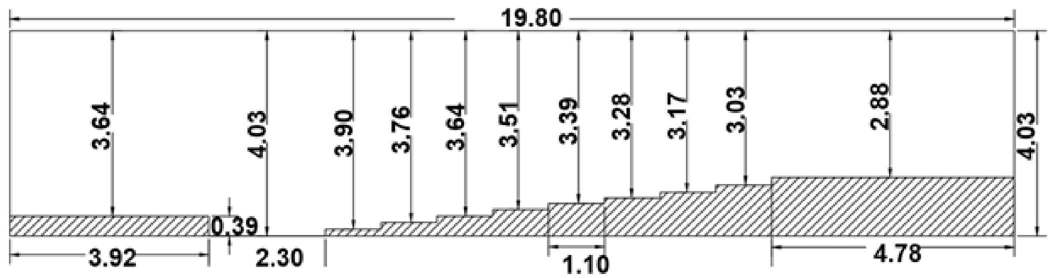


Figure 2. The side view of the hall, and the dimensions are all in meters

2.5 Data acquisition

A dodecahedral sound source Sinus QS-12 which can produce sound suitable for measuring between 50 Hz and 16,000 Hz with a level of 122 dB in the smooth broadband spectrum is used. The required directivity meets the relevant standards, ISO 10140 [20] and ISO 16283 [21]. Stimulation was performed using MLS and ESS in six octave bands (125 Hz – 4,000 Hz). The RIR is recorded with Gras 46AE (omnidirectional), Neumann and Neumann KU 100 (dummy head) microphones. Measurements were performed according to ISO 3382-1. Microphone measurements are transferred to a computer via a Focusrite Scarlett audio interface. The recorded raw sound signals are processed using Dirac v7.1 software. The setup is introduced in Figure 3.

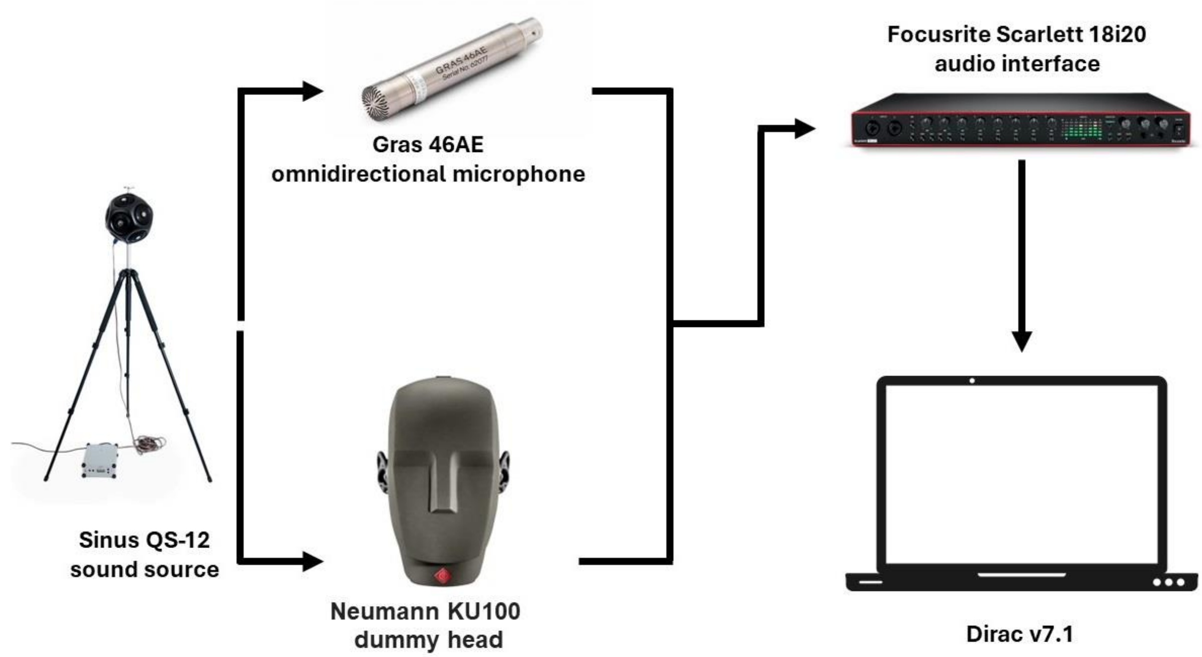
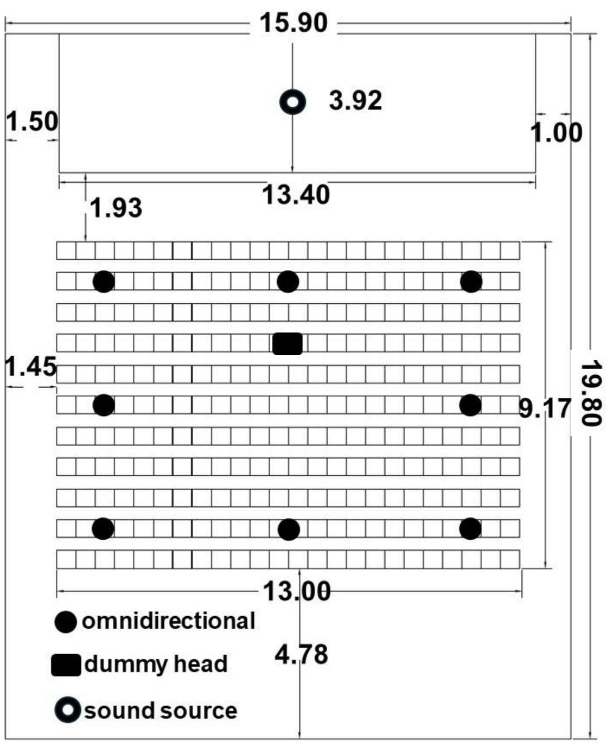


Figure 3. Setup for data acquisition

The measurements were performed on July 10th, 2024, during an 8-hour working period. During the measurements the hall was unoccupied and 2 average temperatures were set, 25ºC and 30ºC. The minimum, maximum and average values of temperature and relative humidity recorded during measurement are tabulated in Table 2. Air conditioning systems were used to maintain the appropriate temperature in the hall and were switched off during the measurements. The background noise level (BNL) of the environment was measured with a Gras 46AE omnidirectional microphone using Sinus Samurai software. During the measurement, the microphone was positioned at the geometric centre of the hall. The BNL of the space was measured as 35.9 dBA. Raw sound data was collected from a total of 10 locations. At 9 locations omnidirectional microphones are used and at 1 location a dummy head is used. The microphones and their locations are shown in Figure 4. For the measurement of the IACC parameter, the dummy head was positioned at the geometric center of the hall.

Table 2. Temperature and relative humidity values during the measurement survey

Temperature (Celsius)			Relative humidity (percent)		
Min	Max	Average	Min	Max	Average
24.08	26.72	25.28	44.72	52.37	47.15
26.72	32.66	30.08	41.12	47.02	44.49



a) Measurement positions

b) Microphones

Figure 4. The floor plan of the space and the positions of the stimulus and the receivers (in meters)

3. RESULTS

The raw data is processed using Dirac v7.1, and acoustic parameters are derived. The parameters obtained through MLS stimulus are tabulated in Table 3 and Table 4 for 25ºC and 30ºC, respectively. For comparison, the parameters obtained through ESS stimulus are also tabulated in Table 5 and Table 6 for 25ºC and 30ºC, respectively.

The parameters RT, EDT, Ts, C80, and D50 are derived in 6 octave bands i.e. 125 Hz – 4,000 Hz. The other parameters, BR and RASTI, are given in Tables 3 to 6 according to their definitions, as they are derived as ratios or averages. The definitions are given in Equation 1 and Equation 7. The values of IACC parameter are measured only through the ESS stimulus and they are tabulated in Table 5 and Table 6 for two different temperatures.

Table 3. Acoustic parameters derived from MLS stimulus-response at 25ºC

Octave (Hz)		125	250	500	1,000	2,000	4,000
RT (s)		0.69	0.73	0.74	0.75	0.87	0.78
EDT (s)		0.51	0.55	0.54	0.60	0.66	0.68
Ts (ms)		51.73	42.41	38.45	39.93	41.41	41.58
C80 (dB)		8.82	8.39	8.84	7.61	7.29	7.10
D50		0.75	0.74	0.76	0.73	0.72	0.70
BR	0.87						
RASTI	0.67						

Table 4. Acoustic parameters derived from MLS stimulus-response at 30ºC

Octave (Hz)		125	250	500	1000	2000	4000
RT (s)		0.49	0.54	0.55	0.61	0.72	0.67
EDT (s)		0.43	0.50	0.61	0.56	0.59	0.64
Ts (ms)		46.60	43.05	39.53	34.98	37.37	39.30
C80 (dB)		10.20	8.78	8.17	8.80	8.19	7.59
D50		0.77	0.77	0.72	0.76	0.76	0.72
BR	0.90						
RASTI	0.68						

Table 5. Acoustic parameters derived from ESS stimulus response at 25ºC

Octave (Hz)		125	250	500	1,000	2,000	4,000
RT (s)		0.69	0.73	0.74	0.75	0.87	0.78
EDT (s)		0.53	0.57	0.56	0.67	0.74	0.72
Ts (ms)		53.44	43.01	38.66	40.43	41.19	42.04
C80 (dB)		8.39	8.37	8.86	7.52	7.35	7.08
D50		0.74	0.74	0.76	0.72	0.73	0.70
BR	0.95						
IACC		0.98	0.81	0.42	0.63	0.65	0.35
RASTI	0.71						

Table 6. Acoustic parameters derived from ESS stimulus response at 30ºC

Octave (Hz)		125	250	500	1,000	2,000	4,000
RT (s)		0.71	0.73	0.68	0.74	0.83	0.76
EDT (s)		0.47	0.57	0.59	0.59	0.68	0.68
Ts (ms)		51.81	43.70	38.88	37.55	39.01	41.43
C80 (dB)		9.09	8.41	8.62	8.52	7.68	7.28
D50		0.75	0.75	0.74	0.74	0.74	0.71
BR	1.02						
IACC		0.98	0.85	0.45	0.65	0.63	0.36
RASTI	0.71						

The optimum RT depends on the type of music and the number of musical instruments on the stage. The volume of the hall studied is 1,077 cubic metres. The optimum reverberation time for symphonic music in this volume is around 1.4 s. The derived RT values show that the hall is not suitable for performing symphonic music.

Sufficient early vocal energy is crucial for speech intelligibility and D50 is a suitable indicator to assess this. The expected value for D50 for good speech intelligibility is 0.5 and above. The other relevant descriptor is RASTI, which is expected to be 0.6 and above in a multipurpose conference room to ensure the quality of oral communication. It can be seen from Tables 3 to 6 that the values of D50 and RASTI are well above the quality thresholds, indicating that the investigated multipurpose hall is suitable for conferences. The optimum values for RT are between 0.7s and 1.2s for speech, which should be about 1s for a hall of 1,000 cubic metres. Although the measured RT value of the studied hall is not optimal, it is within the optimum range.

In what follows, how the derived acoustic parameters change according to the stimulus and temperature is analysed on a parameter basis.

RT, EDT, C80, D50 and Ts values measured in response to ESS and MLS stimuli are compared in Figure 5. It is observed that the differences between the response curves are significant for RT parameter, especially at low frequencies. The change in the temperature amplifies the difference: The average of differences in RT are 20.7% and 23.8% at 25ºC and 30ºC, respectively. For EDT parameter, which is a measure of early reflections, the difference in responses to 2 different stimuli is moderate. According to these results it can be deduced that the effect of stimulus is more dominant for late reflections.

C80, a sound energy parameter, is used as an indicator of the clarity of the music. The measured values are far from the ideal range of -3.2 dB to 0.2 dB. The C80 values measured in response to 2 different stimuli at 25ºC are close in all 6 octave bands, but the average difference increased from 1.5% to 7.2% when the temperature increased. The same is true for D50 and Ts parameters.

In Figure 6, average differences observed in RT, EDT, C80, D50, and Ts at 25ºC and 30ºC are compared. It is observed that the measured values tend to deviate more as the temperature increases. However, the differences are slightly more moderate when the hall is stimulated using ESS. In the MLS technique, it is assumed that the system (hall) behaves linearly and does not change over time. When these assumptions are not met due to temperature changes and similar reasons, problems may arise in measurements. The ESS method is recommended because it separates harmonic distortion and gives higher impulse-to-noise ratios (INR) under usual test conditions [3-6, 11].

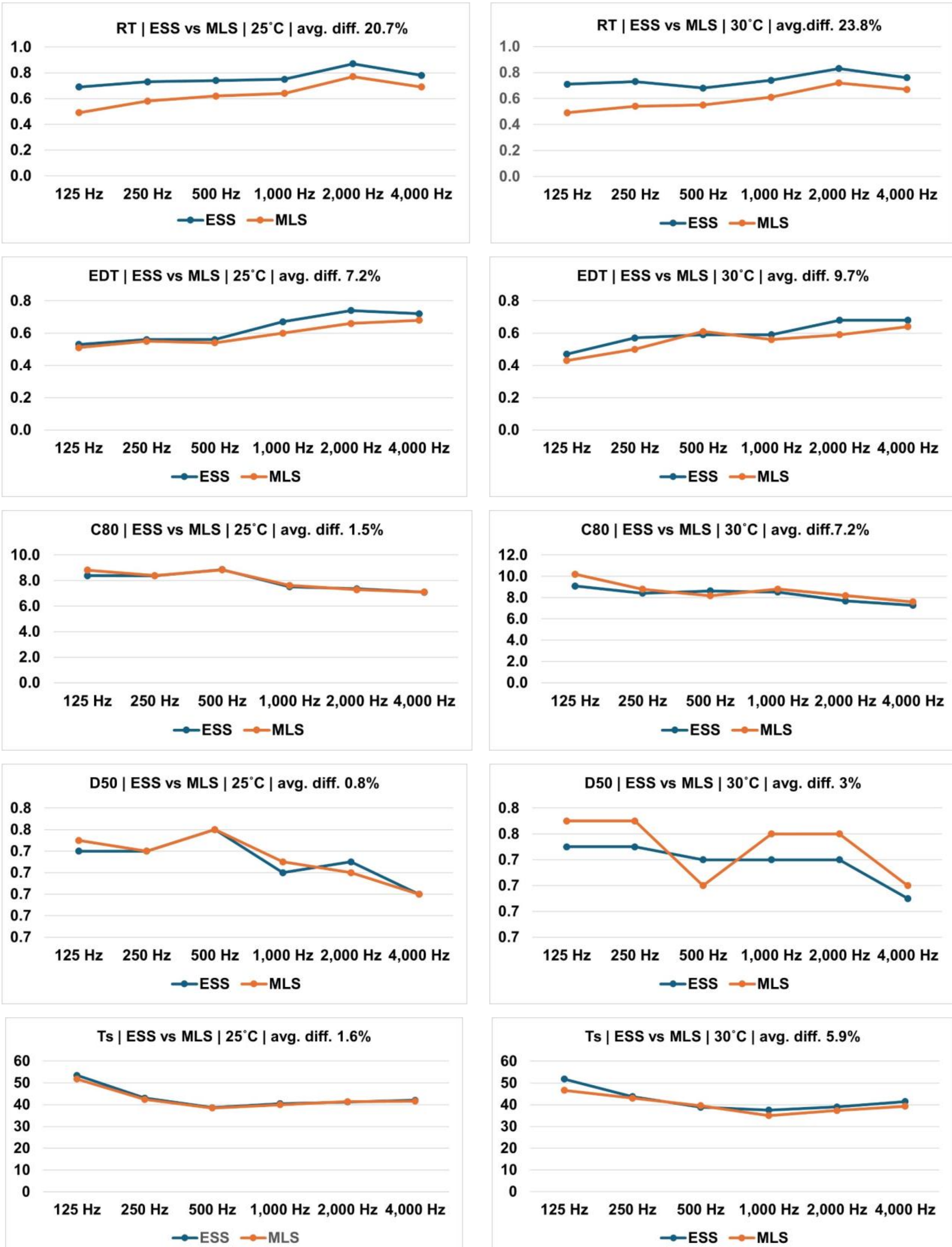


Figure 5. Average differences in RT, EDT, C80, D50, and Ts in response to ESS and MLS stimuli

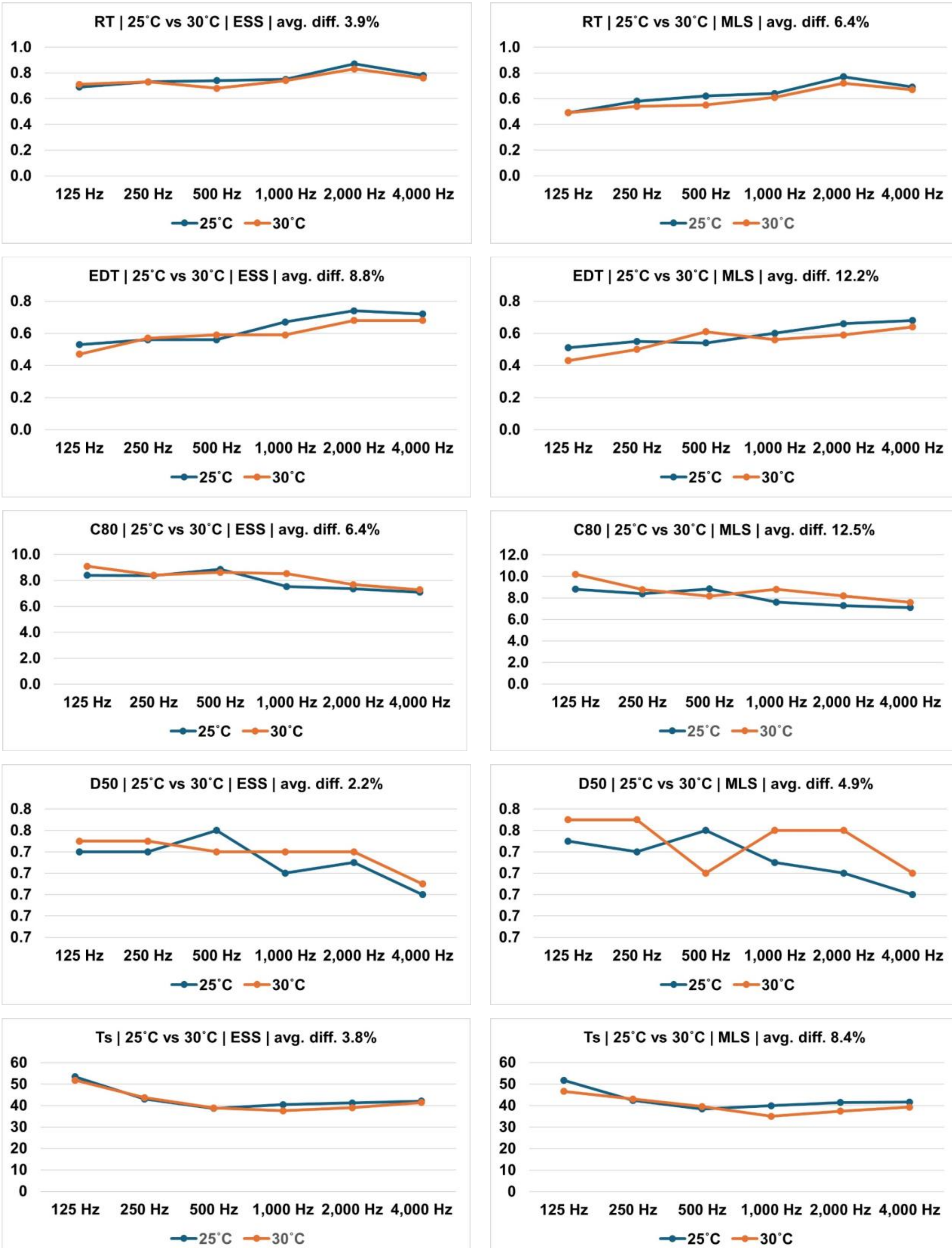


Figure 6. Average differences observed in RT, EDT, C80, D50, and Ts at 25ºC and 30ºC

The temperature differences also alter the IACC parameter which is a measure of binaural hearing. The measured results are compared in Figure 7.

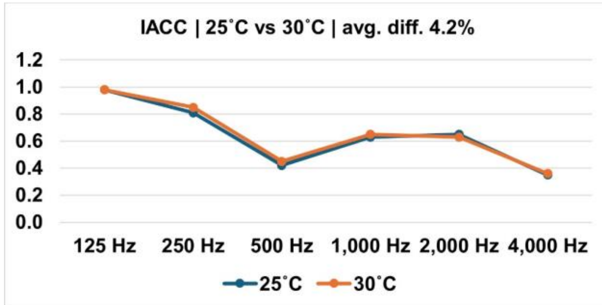


Figure 7. Average differences observed in IACC in response to ESS stimulus at 25ºC and 30ºC

It is desirable that BR, which is one of the important parameters for concert events, has a value of unity. When it is at the ideal value, it indicates that there is a balance between low and medium frequencies in the response of the venue. However, BR and RASTI parameters contradict each other. High BR values are not desirable for speech intelligibility. The BR and RASTI parameters, measured in response to ESS stimulus at 25ºC and 30ºC, are compared in Figure 8.

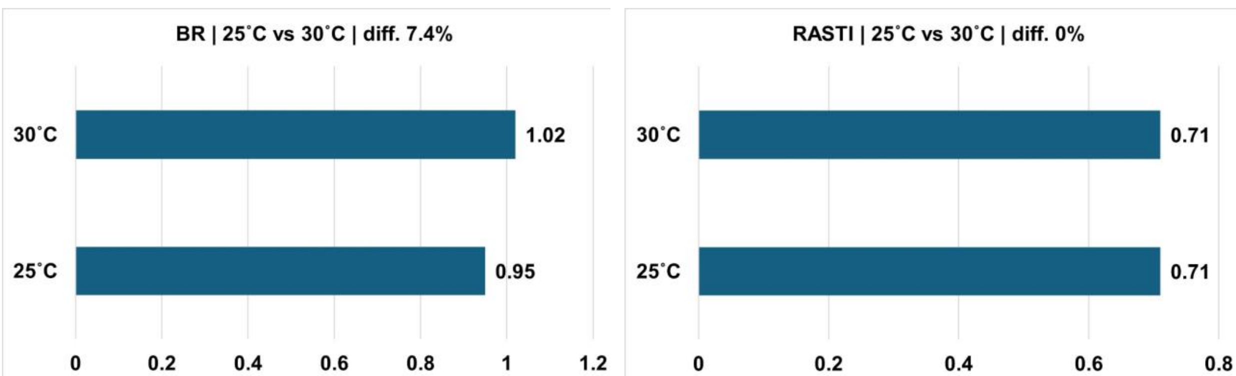


Figure 8. Differences observed in BR and RASTI in response to ESS stimulus at 25ºC and 30ºC

Temperature change increases the value of BR parameter. From this point of view, although the temperature increase seems to be positive, it is actually not. The reason is that it only increased BR; BR increased by 7.4%, while RASTI, an objective measure of speech intelligibility, did not change.

4. CONCLUSION

The results obtained showed that when dynamic variables such as temperature change are taken into consideration, it is more appropriate to make measurements with ESS excitation. This result is consistent with the related studies in the literature [3-5, 7-11].

The obtained results show that acoustic parameters are sensitive to temperature variations. In the initial design, it is generally assumed that the temperature value will remain constant. Considering that the acoustic performance may change negatively due to temperature changes, it is important to take every precaution to keep the temperature constant.

In the measurement survey, the reverberation time (RT), early decay time (EDT), clarity (C80), definition (D50), centre time (Ts), inter aural cross correlation (IACC), bass ratio (BR), and rapid speech transmission index (RASTI) are derived from the raw data. The acoustic performance is evaluated according to the raw data measured in response to exponential sine swept (ESS) stimulus at 25ºC. When the acoustic performance of the measured multipurpose Alev Alatlı Conference Hall is evaluated, the following conclusions can be drawn:

- The average value of RT is 0.76 s. This value is within the optimal range of 0.7 s-1.2 s defined for speech intelligibility. In this volume of 1.077 cubic metres, the optimal value defined for music is 1.4 s. Considering the measured value, it is understood that the volume will not provide an ideal experience for music performances.
- The average values of EDT and C80 are 0.63 s and 7.93 dB. EDT and C80 are more relevant for music performances and their impacts on speech intelligibility are very limited.
- The average value of D50 is 0.73 (or 73%). This value should be higher than 0.50 (or 50%) for a good speech intelligibility. It is well above the threshold. D50 is more concerned with speech intelligibility and its impact on musical performances is rather limited.
- The average value of Ts is 43.13 ms. For ideal speech intelligibility, this value should be below 100 ms. Since it is well below the defined threshold, it can be deduced that the hall is suitable for conference events. On the other hand, the measured value is not well suited for musical performances, where the expected Ts value is 100 ms-150 ms.
- The IACC (3) which refers to the early IACC calculated only the three middle octaves, 500 Hz, 1,000 Hz, and 2,000 Hz, is measured as 0.57. This parameter is more relevant for musical performances and is expected to be below 0.4.
- The BR value is measured as 0.95. It is desirable that the BR, which is an important parameter for musical performance, is between 1.1-1.4. On the other hand, values of 1 and above 1 reduce the intelligibility of speech.
- The RASTI value is measured as 0.71. The RASTI value is moderate between 0.45 and 0.59; good between 0.6 and 0.74; above 0.75 indicates excellent speech intelligibility.

When the measurement results are compared with the relevant standards and literature, it is evaluated that the multipurpose Alev Alatlı Conference Hall is quite sufficient for conference events, commemorations and celebrations, but not far from the sufficient level for musical performances.

5. ACKNOWLEDGEMENT

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