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ACOUSTICAL ANALYSIS AND EVALUATION OF CULTURAL CENTERS AT GAZIANTEP UNIVERSITY

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Kadir Kürşad AYIK

ABSTRACT

ACOUSTICAL ANALYSIS AND EVALUATION OF CULTURAL CENTERS AT GAZIANTEP UNIVERSITY

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M.Sc. in Engineering Physics

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Gaziantep, one of the oldest cultural centers in the Southeastern Anatolia Region, is located on the historical Silk Road. The main objective of this thesis is the analysis of current acoustical performance of Gaziantep University Auditorium and Atatürk Cultural Center which are the most important centers of these cultural activities to carry out. Despite the fact that both salons are used as multipurpose halls, there are no variable panels (or any acoustic solution) in volume. In this context, the assessments were made on the basis of subjective and subjective parameters based on room acoustics. The measurements of the obtained acoustic parameters were compared with the results obtained in the ODEON acoustic analysis program for accuracy. The results were analyzed on the basis of the room acoustic criterion of multipurpose halls, and some suggestions were made to improve the acoustical performance of both halls.

Key words: Acoustical performance, Multi-purpose hall, Room acoustics, Acoustic parameters, Reverberation time.

ÖZET

GAZİANTEP ÜNİVERSİTESİNDEKİ KÜLTÜR MERKEZLERİNİN AKUSTİK ANALİZİ VE DEĞERLENDİRİLMESİ

AYIK, Kadir Kürşad
Yüksek Lisans Tezi, Fizik Mühendisliği Bölümü
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Güneydoğu Anadolu Bölgesinin en eski kültür merkezlerinden birisi olan Gaziantep, tarihi İpek Yolu üzerinde konumlanmıştır. Sahip olduğu bu kültürel faaliyetlerin icra edildiği en önemli merkezleri olan Gaziantep Üniversitesi Oditoryumu ve Atatürk Kültür Merkezi'nin mevcut akustik performans analizi bu tezin temel amacıdır. Her iki salon da çok amaçlı olarak kullanılan salonlar olmasına rağmen, hacimde değişken paneller bulunmamaktadır. Bu kapsamda, değerlendirmeler hacim akustiğinde baz alınan başlıca öznel ve nesnel parametrelerin çerçevesinde yapılmıştır. Elde edilen akustik parametrelerin ölçümlerin doğruluğu için ODEON akustik analiz programında elde edilen sonuçlarla karşılaştırılmıştır. Sonuçlar çok amaçlı olarak kullanılan salonların hacim akustiği kriterleri çerçevesinde analiz edilerek her iki salonunun akustik performansını iyileştirmek için birtakım önerilerde bulunuldu.

Anahtar kelimeler: Akustik performans, Çok amaçlı salon, Hacim akustiği, Akustik parametreler, Çınlanım süresi.

I dedicate this work to my father..

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LIST OF SYMBOLS

c : Speed of sound

κ : Volume elasticity

ρ : Density

λ : Wavelength

f : Frequency

k : Wave number

α : Absorption coefficient

δ : Scattering coefficient

Hz : Hertz

dB : Decibel

D_{50} : Distinctness

C_{80} : Clarity

T_s : Centre time

RT : Reverberation time

EDT : Early decay time

BR : Bass ratio

TR : Treble ratio

G : Strength

STI : Speech transmission index

LF : Lateral energy fraction

CHAPTER 1

INTRODUCTION

There has been observed a significant increase in the number of cultural centers and auditoriums built in recent years with the increasing the number of universities in our country. Generally these places are used for many different entertainments such as concert, theater, opera and etc. In the design of these multipurpose halls, in addition to the architectural functionality and visuality, Architectural Acoustic field plays an important role. To understand the function of Architectural Acoustic, some definitions should be known. For example, acoustics can be defined as a scientific discipline that investigates the physical properties of sound [1]. It can be said that the studies are interdisciplinary because it is a scientific discipline working in many academic fields such as physics, engineering, psychology, audiology, music, architecture and physiology [2] and is divided into many branches such as psychoacoustics, bioacoustics, noise control and architectural acoustics [1].

Architectural acoustics, one of the sub-branches of acoustics, is a scientific discipline that researches in closed spaces and structures to understand the sound environment and use the sound in the best way [3]. Architectural Acoustics has two sub-branches as Building Acoustics and Room Acoustics. Building Acoustics, excluded from the scope of this work, includes sound insulation and noise control [4].

The main subject of this work, which is also the subject of Room Acoustics, dates back to the amphitheaters of the ancient Greek and Roman civilizations. The understanding of room acoustics in a modern sense and a recognition as science has begun at the end of the 19th century, when young Harvard physicist Walter Clement Sabine understood influence on the acoustic conditions of the Reverberation time. The subject of room acoustics is to ensure that the sounds coming from a sound source within the volume reach the ears of all listeners in the best conditions [5].

1.1 Literature Research

The analyzing of room acoustic parameters has been a resource for the work of many scientists since many years. This studies have been examined according to the ISO 3382-1 (2009) Acoustics – Measurement of Room Acoustic Parameters, Part 1: Performance Spaces standard in determining acoustic performance in multipurpose halls and cultural centers. Some of these studies are following.

Acoustical Performance of the Grand of the Atatürk Cultural Center in İstanbul was analyzed in three categories; i) according to geometrical theory, ii) statistical evaluation of the hall, and iii) subjective evaluation of the hall [6]. The analyses of a conference room located in a sample of newly built public buildings was carried out by measuring the requires sound insulation and the reverberation time according to international standards [7]. Acoustics of the Great Hall of the Moscow State Conservatory after Reconstruction in 2010–2011 was performed by comparing the parameters of the hall measured before and after reconstruction [8]. The effect of wood material in comfort of multifunctional rooms have been recently studied [9]. Acoustical performance of Mimar Kemaleddin Hall in Gazi University performed by using ECOTECT v.5.20 simulation program [10].

When the thesis studies are examined, evaluation of acoustic comfort conditions for multipurpose halls have been conducted in three categories. In some of studies, based on objective parameters, the rooms were analyzed only by a simulation program [2, 13, 15, 16, 17, 19, 21]. The other part of papers the calculation was carried by using field measurements. But the studies of [4, 11, 14, 18, 20, 22] was used both simulation program and field measurements. There have been a few studies performed both objective parameters and subjective parameters by survey studies in the halls for improving acoustical comfort of rooms.

1.2 Object of the Thesis

In this study, the Cultural centers in Gaziantep University will be evaluated acoustically with the acoustic modeling programs and acoustic measurement systems by using subjective and objective evaluation methods.

Basically for this purpose, the analyses are carried out in three steps;

i. Examination of analysis of the existing situation by field measurements and evaluation in Cultural Centers in Gaziantep University.

ii. Modeling of the halls which are calibrated according to measurement values and reflect the existing situation with ODEON software.

iii. Comparing the obtained results with the standard and literature values and to present acoustic proposals for the improvement of the existing situation in case of need.

The organization of this thesis is arranged as follows. It consists of five main sections and annexes, while all these stages are being evaluated. The Introduction part represents the aim and general description of thesis. Chapter 2 deals with the basic information about the physical properties of sound and the behaviors of sound in enclosed spaces.

In the third chapter, room acoustics parameters used in the evaluation of cultural centers are given. Room acoustics parameters are examined under two headings as objective and subjective acoustic parameters. Objective parameters are explained together with the calculation methods, and the values in the literature related to these parameters are compiled.

After giving general information about Cultural Centers of Gaziantep University, evaluations made by field measurement method are mentioned in Chapter 4. In the following section, the study and acceptance of the simulation program to evaluate the acoustical parameters in the culture centers are mentioned. Calculations were made in the acoustic simulation program on the selected room acoustical parameters for the cultural centers to be examined, and the obtained values are shown on the graphs, figures and tables. Finally, comparison of the values obtained with the measured values and the proposed values are given.

The general discussions and conclusions about the research are included in final chapter.

CHAPTER 2

FUNDAMENTALS AND DEFINITIONS

In this section, the definition of sound, its characteristics and the distribution of sound in enclosed spaces are discussed.

2.1 Sound and Speed of Sound

Sound is a sensation that is produced at the ear with very low pressure fluctuations in the air [23]. These pressure fluctuations around the equilibrium pressure of the environment must have certain properties in order to be perceived as sound. For the formation of sound, there is a need for a sound source, an elastic medium in which pressure fluctuations can be made and the presence of a receiver [24].

The sound speed c in a fluid is given by

$$c = \sqrt{\frac{\kappa}{\rho}} \quad , (ms^{-1}) \tag{2.1}$$

where, ρ is the density, and κ is the volume elasticity.

In the case of a gas, the pressure variations associated with the sound wave are adiabatic, thus, when the ratio of specific heats under conditions of constant pressure and constant volume is γ.

$\kappa = \gamma P_0$ where P_0 is the atmospheric pressure.

In air at $0°C \ and \ 1 \ atm \ of \ pressure, \gamma = 1.41$,

$P = 101300 \, Nm^{-2}(or Pa) = 1013 \, mbar \quad \rho = 1.29 \, kgm^{-3} \ and \ c = 331.5 \, ms^{-1}$.

Since γ varies with temperature while the atmospheric pressure remains substantially constant, at $t°C$ the sound speed is [25],

$$c = 331.5\sqrt{1+\frac{t}{273}} \quad ,(ms^{-1}) \tag{2.2}$$

2.2 Physical Properties of Sound: Frequency, Wavelength, Wave Number

There is a single frequency (f) associated with a simple harmonic wave. This frequency, the number of cycle in one second, is dependent on the vibration of the sound source, and the frequency is independent of the material through which the sound is transmitted for non-dispersive sound transmission.

The period is defined as the time required a one complete cycle for a wave. The period is indicated by the letter T. There is a relation of $T = 1/f$ between period and frequency. The unit of the frequency is Hertz (Hz) and it is the same as the unit cycle/sec [26].

Wavelength is the distance between repeating units of a wave pattern. It is commonly represented by the Greek lambda (λ). The wavelength is inversely proportional to the frequency, so the frequency decreases as the wavelength becomes longer. The relationship between λ, c and f is

$$\lambda = \frac{c}{f} \tag{2.3}$$

The other parameter that is used in analysis of sound waves is the wave number (k), which is defined by:

$$k = \frac{2\cdot\pi}{\lambda} = \frac{2f\cdot\pi}{c} \tag{2.4}$$

2.3 Sound Pressure, Sound Pressure Level

The vibrations in the sound wave do not occur at all points in the same phase. This indicates that particles in some regions are pushed or compressed together and pulled or rarefied in other regions. For this reason, a diversity is observed under the effect of the sound wave in the gas density and pressure;

both of which are functions of time and position. The difference between the instantaneous pressure and the static pressure is called the sound pressure.

The frequencies where the hearing is most sensitive are in the range of 500 Hz - 5000 Hz. The intensity of the threshold of pain is 13 times greater than the perceived intensity of the threshold of hearing. Therefore, it would not be more practical to express the strength of the sound signal with sound pressure. Instead, a logarithmic expression is used which is called *Sound Pressure Level* for this purpose; defined by

$$SPL = 20 \cdot \log(\frac{p_{rms}}{p_0}) \quad , (dB). \tag{2.5}$$

In this equation, p_{rms} stands for the 'root-mean-square' pressure. The quantity p_0 is an internationally standardized reference pressure; its value is 2×10^{-5} Pa, which corresponds roughly to the normal hearing threshold at 1000 Hz [27].

2.4 Decibel

In the theoretical studies of acoustic phenomena, it is normal to express sound pressure, sound intensity and sound power with Pa, $W \cdot m^{-2}$ and W, respectively. However, it is better to express these quantities in logarithmic scales for practical measurements.

The logarithmic scale used to describe the sound levels is the decibel scale. One decibel is the energy or power ratio, r, defined by

$$\log r = 0.1 \tag{2.6}$$

The definition is become $\log r = 0.05$ for sound pressure or particle velocity ratios. One of the most important aspects of using decibel is that it is a relative measure and that each measured quantity is expressed as a ratio to a reference value [28].

In fact, the level is a dimensionless quantity, but the unit of bel is given in honor of Alexander Graham Bell. The history of the development of the bel unit is described by Huntley (1970) [26].

2.5 Behavior of Sound

When sound is produced in an enclosed space it is reflected, absorbed, refracted, diffused, diffracted and transmitted at various rates in accordance with the nature of the structure.

2.5.1 Reflection

Reflection occurs when the dimensions of an obstacle are larger than the wavelength of the sound. At this stage, the sound ray acts as a light ray and, for an obstacle with a flat surface; the reflected ray is separated at the same angle when the rays approach it, so that the beam angle is equal to the reflection angle. The amount of reflected waves depends on the smoothness, size and softness of the materials. In the case of an enclosed space, the sound waves continually strike each side of the enclosed space until the sound energy is zero [29].

2.5.2 Absorption

When sound waves hit an object, high frequency sound waves are reflected off the object. At this time, however, some of the sound waves are absorbed by the object. The fraction of sound energy which is absorbed by an obstacle is called its absorption coefficient. Absorption varies according to the material properties. The sound absorption coefficient is the ratio of the absorbed sound energy to the incident sound energy. This value ranges from 0 to 1. Porous and soft materials have higher absorption coefficients, while solid and hard materials are lower [29].

2.5.3 Refraction

This phenomenon occurs when a sound ray enters a different medium at an angle. The sound ray bends because of the different speed of the sound wave in the two media [29].

2.5.4 Diffusion

Diffusion is the scattering or random redistribution of a sound wave from a surface. It takes place when the surface depths of hard surface materials are close to the wavelength of the sound. When a satisfactory diffusion is obtained in an enclosed space, the audience of the room will have a sense of sound coming from all directions at equal levels [29].

2.5.5 Diffraction

Sound waves can pass through the hole in an object. If the width of the hole is equal to the wavelength, the sound ray breaks at an angle of 180 degrees and continues as a new sound source. If the width of the hole is larger than the wavelength, the sound wave will continue to run without being broken [29].

2.5.6 Transmission

In this section, part of the energy of the incident sound wave is transmitted to solid obstacles. This transmitted energy causes the molecules of the solid obstacle to vibrate, which can reproduce the sound. Sound transmitted in this way is referred to as structure-borne sound. When it is generated by mechanical means it is referred to as impact sound. Sound transmitted through the air is known as airborne sound [29].

CHAPTER 3

ACOUSTICAL PARAMETERS IN ROOM ACOUSTICS

Applications related to the level of acoustic comfort that should be provided in the enclosed space are examined within the scope of room acoustics.

In this section, parameters that depend on the physical conditions of room used to determine the acoustic comfort level of a room will be examined and optimum values for the halls will be specified.

The parameters used in room acoustics are divided into two groups, subjective and objective. Objective parameters help scientifically to measure and evaluate subjective parameters.

3.1 Subjective Parameters

Subjective parameters cannot be measured as objective parameters. Physically measurable values give predictable results, but it is not easy to interpret with only the measurable values for music. While one of the listeners may find that the acoustic is adequate, the other may find it insufficient and the solution of these two situations may point to different acoustic parameters. Thus, objective parameters as well as subjective parameters should be simultaneously considered in the hall design.

Beranek (1962) prepared the first work on this scope. This study consists of 18 subjective parameters [30]. In this section, subjective parameters such as intimacy, liveness, warmth, subjective clarity, loudness and brilliance are examined.

3.1.1 Intimacy

Acoustic intimacy is the subjective effect that assesses how the size of the hall that played music is perceived by listeners. For every music style, it is necessary to provide acoustic intimacy in room. Because, it is very important to provide a perception of the volume in terms of acoustically appropriate dimensions. In a room that is said to be intimate, listeners are more likely to feel as part of the staged performance [31, 32].

3.1.2 Liveness

This parameter is directly related with the Reverberation Time. When this parameter is evaluated at a point in enclosed space, the ratio of the sound intensity directly reflected from the source of sound intensity that is reflected at this point is examined [33].

A live room has a long Reverberation Time. The Reverberation Time of the halls is short which is defined as dry and dead. Liveness is a subjective parameter and is related with the Reverberation Time between 350 Hz and 1400 Hz frequencies. The reason for this is that the human hearing perception is more sensitive in the mentioned frequency range [34].

3.1.3 Warmth

It is expected that the Reverberation Times of the bass sounds in music will be a bit higher than the Reverberation Times in the medium frequencies, this gives the music the Warmth. The Bass Ratio parameter is used to determine the Warmth. In order to qualify a room as acoustically Warmth, the BR values must be within the range of the literature. Warmth is missing in rooms with a BR value lower than 1.0. On the other hand, extremely high BR values should be avoided [35].

3.1.4 Subjective Clarity

This parameter is relevant to the fact that sounds are noticeable during a musical performance. It depends on the performance of the musicians and the acoustic conditions of the room.

Subjective Clarity is divided into horizontal and vertical;

i. Horizontal Clarity: It is applied for intermittently played tones and objectively measure the length of the RT and the ratio of the energy of the first reflections to the energy of the delayed reflections.

ii. Vertical Clarity: It is applied for simultaneously played tones and depends on the ability of the musicians, the acoustic characteristics of the room and the attention of the listeners [32].

3.1.5 Loudness

In assessing the acoustic qualities of a hall, it is importance that the perceived sound in the room is sufficiently high. Loudness is a function of the division of a sound energy into the number of people who will share it. This energy is also reduced by the absorption characteristics of people and other materials. The loudness of a certain listener's point consists of two parts, early and late. Both of them have subjective interactions with individual effects and other subjective parameters. The total loudness is measured by the $G - Strength$ objective parameter. An inadequate level of loudness may be annoying, and being overly high can be unbearable [36].

3.1.6 Brilliance

Brightness is defined as "Bright, clear and resonant, rich in harmonized". High frequency sounds of a bright sound reduces slowly. In the halls, high-frequency sounds are naturally reduced by the reason for the absorption of the air. It may be that excessive use of sound absorbing materials such as seats, curtains or the like can cause the brilliance to decrease significantly. In contrast, sound can be made entirely brilliance by electronic amplification [34].

The optimum Brilliance values required in concert halls should be greater than 0.9 and 0.8 for 2000 Hz and 4000 Hz, respectively [35].

$$\frac{2 \cdot EDT_{2000}}{EDT_{500} + EDT_{1000}} \geq 0.9, \frac{2 \cdot EDT_{4000}}{EDT_{500} + EDT_{1000}} \geq 0.8 \tag{3.1}$$

3.2 Objective Parameters

Objective parameters are measurable and computable parameters that directly affect the hall design. Objective parameters can have effects on many subjective parameters.

In this section, the main objective acoustic parameters used in room acoustics evaluation will be explained.

3.2.1 Background Noise and Noise Criteria

For acoustically important rooms, the first criterion to consider for acoustic comfort is the existing noise level at the rooms. Because of the noises inside and outside the hall, the perception of the all events by the audience can decrease the quality and quantity. For this reason, existing noise levels in the saloons should be kept below their specified values [12].

Background noise refers to the total remaining sound in the given position and in the given situation when the examined sounds in an environment are suppressed [37].

Noise Criteria (NC) curves are used when expressing the noise level of the environment in the standards that are valid in our country.

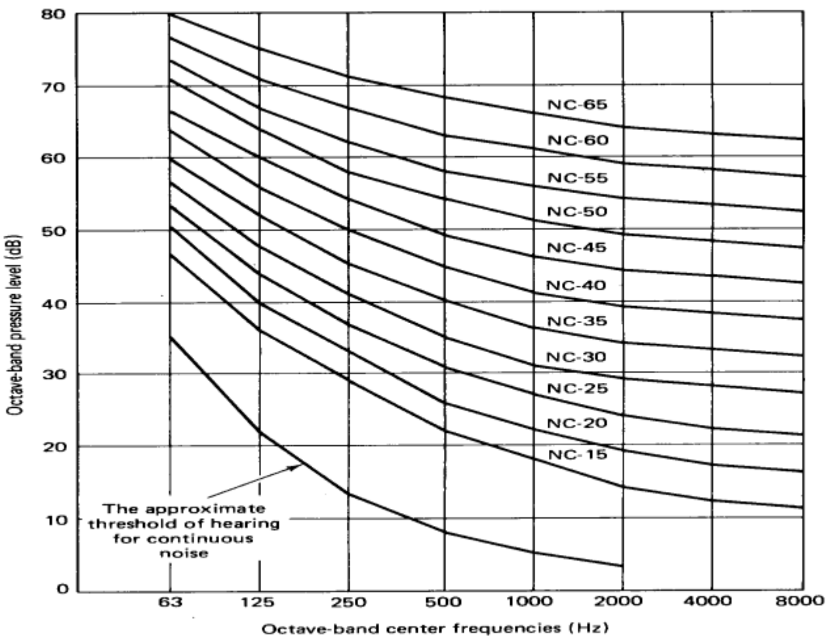

Figure 3.1 NC Curves [38].

The technical definition of the NC curves given in the graph is the arithmetic mean of the sound pressure levels at 1000, 2000 and 4000 Hz. The NC ratio is found by comparing the noise level for a noise measurement with the NC curve, is the lowest NC curve that is not exceeded by the audio spectrum point [39].

Noise level limit values for inside the halls when not in use which were investigated in this study, shown in the Table 3.1, are taken from "Evaluation and administration of environmental noise regulation" (law number 27601) which was published and came into force at June 4th, 2010 in the official journal by the Ministry of Environment and Forestry.

Table 3.1 Noise Level Limit Values for Inside the Halls [37].

Area of Usage	Closed window L_{eq} (dBA)	Open window L_{eq} (dBA)
Theater halls	30	40
Concert halls	25	35
Conference halls	30	40

3.2.2 Distinctness

The *Distinctness* (D_{50}) is the parameter related to the intelligibility of speech, defined by Thiele in 1953, and the ratio of early energy measured by the signal response of the source and the receiver's. It is the ratio of the early sound energy reaching the receiver in the first 50 ms time to the total sound energy and is expressed as D_{50} [30].

The D_{50} is inversely proportional to the Reverberation Time. Distinctness – Definition (Deutlichkeit) D_{50} is defined by

$$D_{50} = \frac{\int_0^{0.05} p^2(t)dt}{\int_0^{\infty} p^2(t)dt} \tag{3.2}$$

where;
$p^2(t)$: sound pressure, (Pa).

In Figure 3.2, it is shown that the D_{50} parameter is related to intelligibility which is the result of studied by Boré [27].

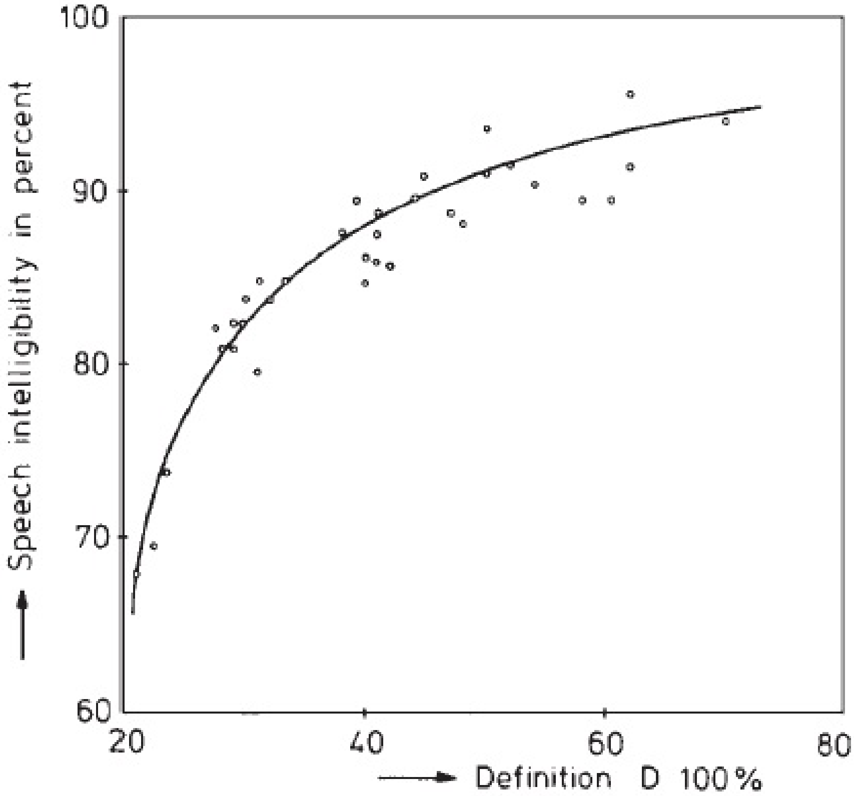

Figure 3.2 Relationship Between Syllable Intelligibility and 'Definition' [27].

The D_{50} values above 50% provide 90% speech intelligibility as can be seen in the Figure 3.2. In this respect, values above 50% of the D_{50} parameter are regarded as acceptable values [27].

3.2.3 Clarity

Reichardt determined that the time for integration of direct sound and early reflections that reach after direct sound to the audience was limited to 80 ms in order for the music to be perceived clearly. This parameter was obtained by Thiele's speech intelligibility parameter. The *Clarity* (C_{80}) is the index of the ratio of the early sound energy to the late sound energy reaching the audience in the first 80 ms time interval and expressed in dB [30],

$$C_{80} = 10 \log \frac{\int_0^{0.08} p^2(t)dt}{\int_{0.08}^{\infty} p^2(t)dt} \quad , (dB) \tag{3.3}$$

The C_{80} is the room acoustics parameter used to separate the first sound energy and the reverberant sound energy emitted from the source. The D_{50} related to speech, while the C_{80} parameter is used to describe the clearness and intelligible of the music. Even though the intelligibility of the Room is sufficient for music, it may be insufficient for speech. If this parameter is low, it states that the reverberation in the volume is higher. If the early and late sound energies are equal, $C_{80} = 0$. For places where the music can be clearly understood, the Clarity parameter has a positive value [12].

Table 3.2 Typical Range for Clarity Parameter.

Bibliography	Typical Range [dB]
[30]	-2 $\leftrightarrow$ +2
[36]	-4 $\leftrightarrow$ +4
[40]	-5 $\leftrightarrow$ +5

3.2.4 Centre Time

In some cases, the reflections within the room can bring temporary and sudden cuts on the impulse response that do not attach much importance to the perception of the ear. This parameter, developed by Cremer, is defined as the center of gravity of the square of signal response. Therefore, it is also known as "Point of Gravity".

$$T_s = \frac{\int_0^\infty t \cdot p^2(t)dt}{\int_0^\infty p^2(t)dt} \quad , (ms) \tag{3.4}$$

It have effects on the parameters of EDT, D_{50} and C_{80}. The lower the *Centre Time* (T_s), the higher the early sound energy, and as this value drops, sound clarity increases. If the T_s has too high value, the late energy is too much and the reverberation is increasing. According to ISO 3382-1 standard, the T_s parameter should be between 60 ms and 260 ms [14, 40].

3.2.5 Reverberation Time

One of the most important acoustic evaluation criteria in room acoustics is the *Reverberation Time* (RT) parameter, it was discovered by W.C. Sabine in

1895-1900.

After the sound source is turned off, the sound in the room is called reverberation by attenuation with consecutive reflections. The time required for the sound pressure level in the air to decrease by 60 dB is defined as the reverberation time.

Sabine found after lots of experimental results that the larger the volume of the room, the longer the RT. Likewise, he realized that the length of reverberation is so short, if the materials and objects in the room are so absorbent. Thus,

$$RT = K \cdot \frac{V}{A} \quad , (ms) \tag{3.5}$$

where; K is the constant, $K = 0.161$ and A is the total absorption, (sabin).

A can be obtained by,

$$A = S \cdot \alpha \quad , (m^2) \tag{3.6}$$

where $S(m^2)$ is the total surface area inside the room and the average absorption coefficient is α. The total absorption is expressed by

$$A = \sum S_i \cdot \alpha_i \quad , (m^2) \tag{3.7}$$

where α_i is the absorption coefficient of the corresponding area S_i and $S_i \cdot \alpha_i$ is the sum of the absorptions of all the different surfaces in the room.

When there are furniture and people present for which the surface area cannot be determined, each individual unit of absorption described as A_j, (m^2) is used. Therefore, the total absorption can be obtained as follow

$$A = \sum S_i \cdot \alpha_i + \sum A_j \quad , (m^2) \tag{3.8}$$

where A is called equivalent absorption area, and α_i is variable depending on the frequencies of sounds [25].

Table 3.3 Typical Mid-frequency RT Values [1].

Type of Facility	Typical Range [s]
Conference Room	1.0
Drama Theater	1.0
Multipurpose Auditorium	1.3 ↔ 1.5
Rock Concert Hall	1.5
Opera House	1.4 ↔ 1.6
Symphony Hall	1.8 ↔ 2.0

Table 3.4 Typical Range for Reverberation Time.

Bibliography	Typical Range [s]	
	Speech	Music
[25]	0.88 ↔ 1.18	1.46 ↔ 1.66
[30]	0.7 ↔ 1.0	1.8 ↔ 2.2
[41]	-	1.7 ↔ 2.3
[46]	-	1.6 ↔ 1.8
[52, 53]	0.7 ↔ 1.0	-

3.2.6 Early Decay Time

The *Early Decay Time* (*EDT*) is the parameter that examines the first reduction part of the sound and compares it with the reverberation time. To describe more technically, EDT is the six times of the duration required for the level of sound being reduced by 10 dB since the source was turned off. The reason of multiplying of this time by 6 is to compare it with the reverberation time. Thus, if there is any discrepancy between the decay in the early part of the sound and the reverberation time, it can be observed [34].

The EDT is a parameter related to the damping of the sound in the same manner as Reverberation Time is. RT and EDT values can be quite close to each other even be equal in a room which has diffuse sound field [30].

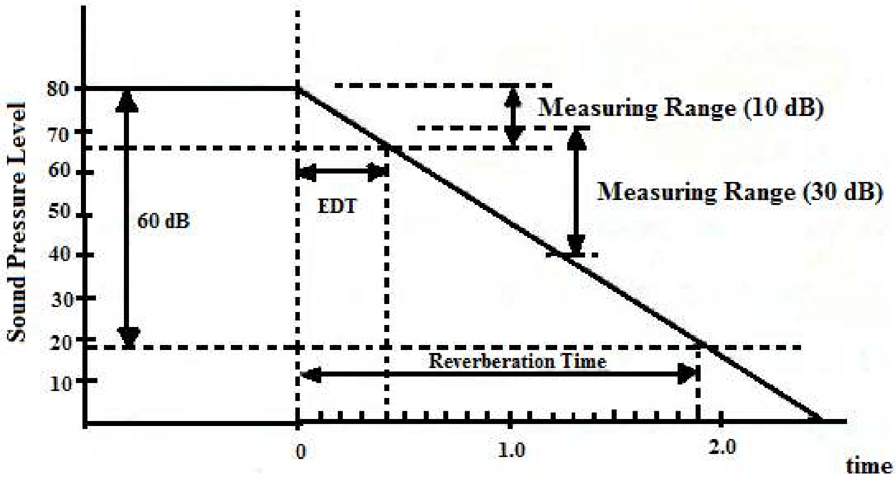

Figure 3.3 Determination of EDT and RT on the Decay Curve [47].

$$EDT = 6 \cdot t_{10} \quad , (s) \tag{3.9}$$

where,

t_{10}: Elapsed time for first 10 dB decrease of sound, (s).

Early reflections allow the investigation of the effects of room geometry over Room Acoustics as they come from identifiable surfaces. On the other hand, RT is independent of the room geometry since it is made up of reflections from almost all room surfaces. For this reason, while RT values are physically significant, EDT values are more closely related to the subjective liveness parameter. But all this should not mean that the last part of the decay is not entirely important. On the contrary, the last part of the decay gives a feeling of liveness for music. The short EDT gives clarity to the music, while the long RT brings liveliness. Long EDT values cause to increase the liveness in the hall, and reduced intelligibility due to the decrease in clarity [30, 35].

Table 3.5 Typical Range for Early Decay Time.

Bibliography	Typical Range [s]	
	Speech	Music
[30]	-	1.8 $\leftrightarrow$ 2.2
[40]	-	1.0 $\leftrightarrow$ 3.0
[41]	-	1.7 $\leftrightarrow$ 2.3
[46]	-	1.9 $\leftrightarrow$ 2.3
[52, 53]	< 1.0	-

3.2.7 Bass Ratio

The *Bass Ratio* (BR) parameter represents the ratio of the values of 125 and 250 Hz RT to values of 500 and 1000 Hz RT and is shown by the following formula.

$$BR = \frac{RT_{125} + RT_{250}}{RT_{500} + RT_{1000}} \tag{3.10}$$

This parameter is used to determine the subjective Warmth parameter in the halls. As this rate increases, up to a certain value, the sound on the hall is perceived as 'warm'. This acoustic parameter is important for music purposes halls [35].

It is expected that the BR value will be between 1.1 and 1.25 if the RT in a hall is greater than 1.8 s. If the RT falls below 1.8 s, the BR value should be between 1.1 and 1.45 [36].

3.2.8 Treble Ratio

The *Treble Ratio* (TR) is the ratio of the sum of the 2000 and 4000 Hz RT to the RT of 500 and 1000 Hz. This ratio is used to determine the subjective Brilliance parameter and is shown by the following formula [42],

$$TR = \frac{RT_{2000} + RT_{4000}}{RT_{500} + RT_{1000}} \tag{3.11}$$

The TR is an important parameter for music purposes halls as good as BR parameter.

3.2.9 Strength

Acoustically, *Strength* (G) is the value of sound pressure level due to a source in a room relative to the sound pressure measured at a distance of 10 m from a source equivalent to the sound source in the anechoic room, expressed in terms of the following relation [30],

$$G = 10 \log \frac{\int_0^\infty p^2(t)dt}{\int_0^\infty p_A^2(t)dt} \quad , (dB) \tag{3.12}$$

where,
$p_A^2(t)$: sound pressure measured at a distance of 10 m from an equivalent source in anechoic room, (Pa).

At a 10 dB increase or decrease in the G, the perceived loudness at the ear is doubled or falls to half. That is, a change of 10 dB in G value, change the perception of loudness of the sound in the ear by twice. Many parameters depend on this parameter, such as clarity, since the Strength affects the perceptibility of spatial and reverberant effects [43].

Table 3.6 Typical Range for Strength.

Bibliography	Typical Range [dB]
[30]	>0.0
[40]	-2.0 ↔ +10.0
[41]	>3.0
[46]	4.5 ↔ 5.5

3.2.10 Speech Transmission Index

The *Speech Transmission Index* (STI) is an objective measurement method used to determine the intelligibility of speech. Two scientists, Houtgast and Steenken, developed a system that imitate human sound with many qualities in 1973.

This method in the name of Modulation Transmission Function (MTF) consists of a system that imitates speech and physically measures it with a properly designed device. The measured values are related with STI [44].

Table 3.7 The Recommended Range for the STI in ODEON [41].

Subjective Scale	STI Value
Bad	0.00-0.30
Poor	0.30-0.45
Fair	0.45-0.60
Good	0.60-0.75
Excellent	0.75-1.00

The STI specifies the effects of speech transmission on the intelligibility of speech. These effects are determined by analyzing the decrease in energy along the transmission path taken from the source until the sound signal reaches the audiences [45].

3.2.11 Lateral Energy Fraction

The *Lateral Energy Fraction* (*LF*) was derived from subjective tests by Baron and Marshall in 1981, where the Spatial Effect was measured by a linear system. This parameter is calculated by the ratio between the sound energy received by a bidirectional figure-of-eight microphone with its null pointing at the source at first 80 ms and the sound energy received by an omni-directional microphone at the same position at first 80 ms [30],

$$LF = \frac{\int_{0.005}^{0.08} p^2(t) \cdot \cos^2 \theta dt}{\int_{0}^{0.08} p^2(t) dt} \tag{3.13}$$

where;
θ: is the angle made by the lateral reflection with the imaginary axis passing through the ears of the listener at the receiver.

Table 3.8 Typical Range for LF.

Bibliography	Typical Range [-]
[30]	$0.10 \leftrightarrow 0.35$
[40]	$-14.00 \leftrightarrow +1.00$
[41]	>0.25

CHAPTER 4

INVESTIGATION OF THE CULTURAL CENTERS AT GAZIANTEP UNIVERSITY IN TERMS OF ROOM ACOUSTICS

Room acoustics is becoming increasingly important nowadays. The acoustic arrangements of halls have great importance in order to avoid both time and unnecessary expenses while the buildings to be built are in the design phase.

In the scope of this thesis prepared for evaluating the acoustic performance of the existing halls, Gaziantep University Atatürk Cultural Center and Gaziantep University Auditorium were selected as exemplary studies.

For this reason, it was decided to use a computer acoustic simulation program and field measurements to evaluate the room acoustics of the Cultural Centers at Gaziantep University with the three-dimensional model in the context of the acoustic parameters described in Chapter 3.

4.1 Cultural Centers at Gaziantep University

In this section, general information about the location, used materials and structure of Cultural Centers of Gaziantep University will be given.

4.1.1 The Atatürk Cultural Center

The Atatürk Cultural Center (ACC) was built in 1999 with the aim of realizing the activities of the university (concerts, theater, conferences, exhibition activities, etc.) in an integrated manner. After building the Gaziantep University Auditorium, the hall is now mostly used for theater and rarely for concert purposes.

Cultural centers are considered to be sensitive to noise, so when choosing a location, care should be taken to avoid or prevent noise.

The Atatürk Cultural Center is located on the central campus of Gaziantep University, away from the city noises. Figure 4.1 shows the location of ACC in Gaziantep University.

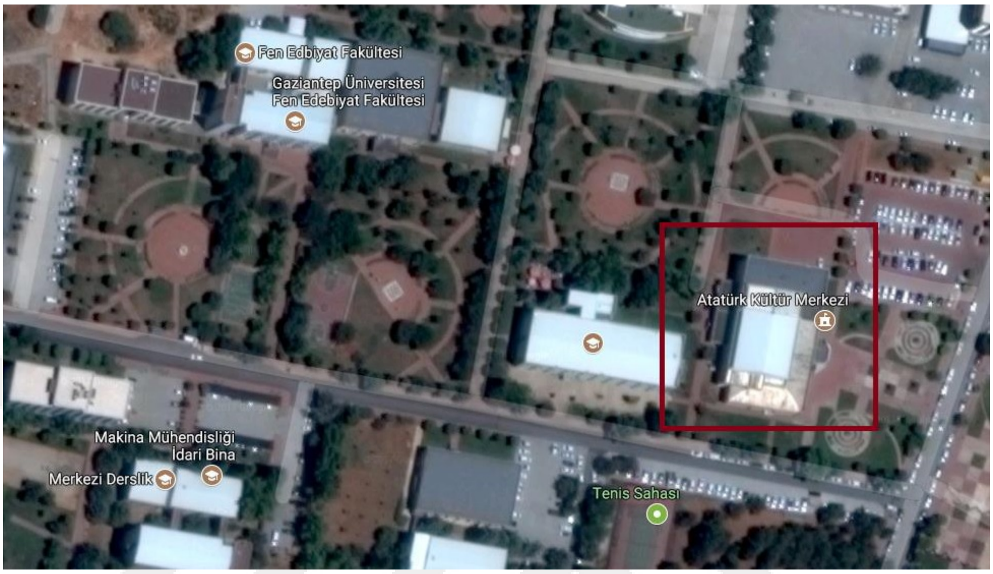

Figure 4.1 Location of ACC in Gaziantep University.

Figure 4.2 The Atatürk Cultural Center.

If the general characteristics of the room are to be examined;

The Hall has a symmetrical plan scheme. It is in the form of a rectangle shoebox-type hall. It has a seating capacity of 477 people.

The hall has three entrances, two from the sides of the hall and one from the back. The entrance for audience opening to foyer area. The floor was designed to be multistage. The stage flooring is made of wooden parquet, the walls are painted on gypsum plaster, the velvet curtain behind it has sound absorbing property. Panels on the side walls of the hall show a feature of a sound diffuser. In the ceiling of the hall, the parts close to the stage are made of flat panels and the other parts are made of hollow plasterboards in rectangular form. The audience area is designed as completely sound absorbent, the seats are velvet covered and the ground is carpeted.

4.1.2 Gaziantep University Auditorium

The Gaziantep University Auditorium, which opened to use in 2014, is located on the central campus of Gaziantep University. The auditorium is frequently used for activities in Gaziantep University, as well as activities in Gaziantep, especially due to its audience capacity. The hall is used for multi purposes, such as international conferences, congresses, concerts, exhibitions. Figure 4.3 shows the location of the Auditorium in Gaziantep University.

Figure 4.3 Location of the Auditorium in Gaziantep University.

The building is located close to a rather busy avenue and is exposed to traffic noise throughout the day. The building is located in a large garden and there are trees between the building and the road. In this way, the noise generated by the traffic noise has been tried to be minimized.

If the general characteristics of the auditorium are to be examined;

The Hall has a symmetrical plan scheme. It has the characteristics of a fan shaped-type hall as a form. The fan shaped-type hall is preferred when the size grows and the biggest advantage it brings is that the audience is closer to the sound source. Auditorium capacity is 870 in parterre and 568 in balcony, with a total of 1438 people.

Figure 4.4 The Auditorium.

There are nine entrances of the auditorium in total, two from the downstage, two from the sides of the hall and two from the back, and three from the back of the balcony. The floor was designed to be multistage. The entrance for audience opening to foyer area.

The stage flooring is made of wooden parquet, the walls are painted on gypsum plaster, the velvet curtain behind it has sound absorbing property. The side walls of the hall are completely wood-covered and have sound diffuser feature. Fabric covering panels are used in the side wall area on the balcony.

On all surfaces facing the stage, perforated panels with a high absorbency are used to prevent the sound coming from the stage. The wooden panels on the ceiling are angled to reflect the direct sound to the audience area.

The audience area is designed as completely sound absorbent, the seats are velvet covered and the ground is carpeted.

4.2 Field Measurements

Nowadays, acoustic measurements can be made on the field measurements or in computer software with suitable measuring instruments. Since both methods have both positive and negative aspects, two methods have been widely used in the evaluation and improvement of existing halls. For this reason, it is appropriate to use these two methods together in the halls which are evaluated.

In field measurements, which are the first method used to analyze the acoustic performances of the halls, objective parameters were measured while the halls were unoccupied and evaluated together with the simulation results.

In this study, the measurement of the room acoustic parameters used was made in accordance with ISO 3382, Measurement of Room Acoustic parameters - Part 1: Performance spaces.

In ISO 3382-1 Standard, a number of rules regarding field measurement conditions are given.

i. Measuring system consists of speaker, sound amplifier, sound analyzer and microphone.

ii. The source to be measured should be omnidirectional audio source.

iii. At least two source points should be specified and the sound sources and receivers should be placed in their natural places.

iv. The distance between the source and receiver must be at least 1.5 m.

v. The distance between the source and ground should be 1.5 m.

vi. For the reverberation time measurements, the receiver points must be selected to represent the entire hall, and the receiver must be placed where as possible as in different acoustic conditions on the field. Some examples are the differences for seating areas close to walls, underneath balconies or in spaces which are decoupled.

vii. The microphones should be at least 2 m apart between them and should be placed at least 1m away from the surrounding reflective surfaces and the ground.

viii. The minimum number of receivers to be placed according to the number of listeners in the hall.

4.2.1 Measurement Equipment

All the equipment used during the measurements were calibrated before and after the measurements. The basic equipment used during the measurements; laptop, sound card, sound source, measurement microphone, amplifier and calibration device. The detailed information of the measuring equipment is given in turn.

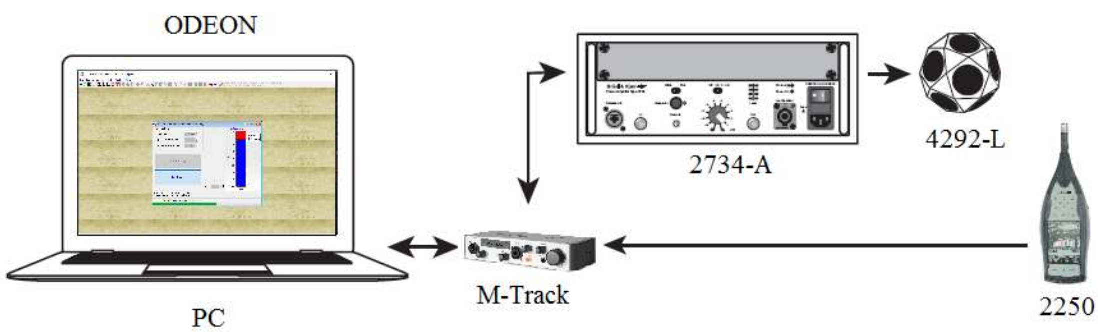

Figure 4.5 Measurement Equipment [48].

The Figure 4.5 was taken from Product Data, DIRAC Room Acoustic Software Type-7841, Brüel&Kjaer and modified on.

Sound Source

The 4292-L model of Brüel&Kjaer, shown in Figure 4.6, used an omnidirectional audio source with twelve-sided loudspeakers during the measurements. This audio source can radiate the sound, accordance with the ISO 3382-1 standard, for each octave band frequency and in every direction.

Figure 4.6 OmniPower Sound Source Type 4292-L [49].

During the measurements, the 2734-A model amplifier from Brüel&Kjaer as shown in Figure 4.7 was used to achieve the required sound pressure level.

Figure 4.7 Power Amplifier Type 2734-A [49].

Microphone, Sound Calibrator and Sound Card

During the measurements; A 2250-type omnidirectional microphone from Brüel&Kjaer, shown in Figure 4.8, is used. This microphone is calibrated to measure the sound level.

Figure 4.8 Hand-held Analyzer Type 2250 [49].

To calibrate the microphone, the 4231 model sound calibrator from Brüel&Kjaer, shown in Figure 4.9, is used.

Figure 4.9 Sound Calibrator Type-4231 [50].

During the measurements, the Two Channel USB Audio Interface - M-Track model sound card of M-AUDIO as shown in Figure 4.10 is used.

Figure 4.10 Two Channel USB Audio Interface [51].

Software

The data received by the Brüel&Kjaer 2250 type microphone and the M-Audio sound card were analyzed using the Odeon13 Combined software, and the acoustic parameter values were obtained.

Besides, the measured EDT and RT values were checked at the same points using the Brüel&Kjaer BZ-7227 Reverberation Time Software.

The measurement screen of the Odeon program used during the measurements is given in Figure 4.11.

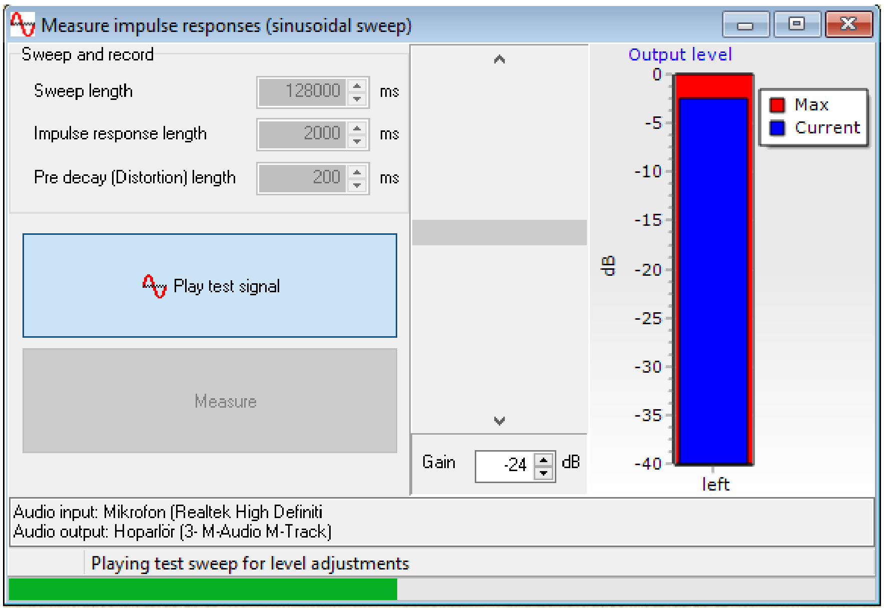

Figure 4.11 Measurement Screen.

4.2.2 Measurement Conditions and Positions

In this study, measurements were made when the culture centers were unoccupied and the ventilation systems were working. According to the standard, the temperature and relative humidity of the air inside the room should be within $\pm\ 1°C$ and $\pm$ 5% accuracy [40].

Table 4.1 and Table 4.2 give information about measurement dates, source-receiver numbers, temperature and relative humidity values of Cultural Centers.

Table 4.1 Measurement Conditions of ACC.

Date	30/10/2017 - 31/10/2017
Source Number	2
Receiver Number	8
Temperature	$18.5°C$
Relative Humidity	57%

Table 4.2 Measurement Conditions of the Auditorium.

Date	13/11/2017 - 16/11/2017
Source Number	3
Receiver Number	16
Temperature	$24.1°C$
Relative Humidity	46%

In the measuring halls, the receiver and source points were determined according to the size of the culture centers and design of the rooms. The number of microphones that need to be used according to the number of seating in the Table 4.3 is shown.

Table 4.3 Minimum Number of Receiver Positions as a Function of Auditorium Size [40].

Number of seats	Minimum Number of Microphone Positions
500	6
1000	8
2000	10

In order to get healthy results in the field measurements of the halls, the source, microphone characteristics and corresponding locations are significant. If the source and receiver points are not placed properly in the acoustic measurements, the values of the room acoustical parameters can be obtained differently from the existing ones. Because of this reason, the source and microphones must be placed in accordance with the standards.

The sound source should be placed 1.5 m above ground in accordance with ISO 3382-1 standard. Microphones should be held at 1.2 m above from the ground to be at the same height as the human ear. It is important to ensure that the microphones are not disturbed by direct sound and that the distances between them are at least 2 m and that the positions of the microphones are at least 1 m away from the nearest reflective surface and not too close to the sound source.

During the measurements at ACC, in accordance with ISO 3382-1 standard, the omnidirectional sound source was placed at two points at a height of 1.5 m above the ground according to the natural positions of orators or artists.

Figure 4.12 Location of Sound Source (S1) at ACC.

The number of microphones was determined to be 8 in terms of compliance with the standard, considering the capacity of 477 people of the cultural center. As the building plan is symmetrical, the microphones were placed homogeneously in half of the room. The receiver locations were located at a distance of at least 2 m between them, 1.2 m above the ground and at least 1 m from the surrounding reflective surfaces.

The potential points that have different acoustic characteristics were noted when choosing microphone locations, and they were placed in front of the stage, near the walls, behind the hall. The ventilation system was operating during the measurements.

Figure 4.13 Location of Receiver Point (R1) at ACC.

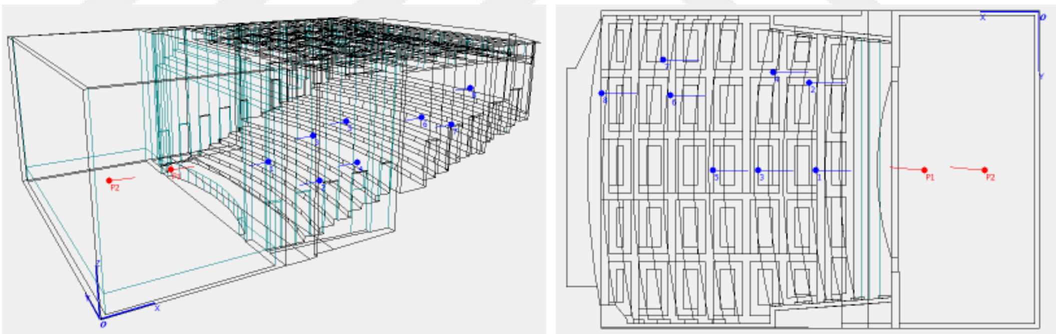

Figure 4.14 Locations of Source and Receiver Points in ODEON at ACC.

During the measurements at the Auditorium, the omnidirectional sound source was placed at three points at a height of 1.5 m above the ground according to the natural positions of orators or artists, as shown in Fig. 4.15.

Figure 4.15 Location of Sound Source (S1) at Auditorium.

The number of microphones was determined to be 16 in terms of compliance with the ISO 3382-1 standard, considering the capacity of 1438 people of the hall. As the room plan is symmetrical, the microphones were placed homogeneously in half of the room. The receiver locations were located at a distance of at least 2 m between them, 1.2 m above the ground and at least 1 m from the surrounding reflective surfaces.

The potential points that have different acoustic characteristics were noted when choosing microphone locations, and they were placed in front of the stage, under the balcony, balcony, near the walls. When the data was being recorded, existing speakers of the room were turned off and the ventilation system was operating.

Figure 4.16 Location of Receiver Points (R2 and R13) at Auditorium.

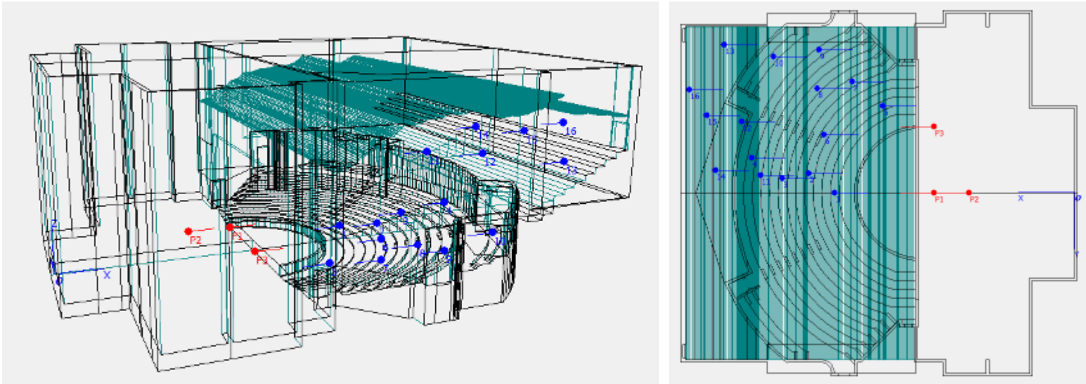

Figure 4.17 Locations of Source and Receiver Points in ODEON at Auditorium.

4.2.3 Results of Field Measurements

The measurements performed for the acoustic parameters to be given in this part of the thesis were repeated three times at each point and the mean values were taken and the receiver value at that point was obtained.

For the selected source points in ACC, 8 receiver points were selected and measurements were taken at these points and the values of the source points (S1, S2) were obtained by taking the averages. As a result; The values given as "Mean Values" are the average values of the source points which give the general mean of the room.

The same process was applied to 3 source and 16 receiver points in the Auditorium.

In the halls;

i. background measurements were performed first,

ii. by using the sweep signal method with ODEON, all the objective parameters defined in Chapter 3 were obtained.

iii. Afterwards, by using the interrupted method, the EDT and RT parameters were measured for control purposes.

As aimed with the scope of the thesis, the results of the objective parameter values are obtained for frequency values between 125 Hz and 4000 Hz.

Field measurement results for Atatürk Cultural Center

In this section, the average values of the field measurement results of 2 source and 8 receiver points at ACC will be shown by tables and graphs. All values obtained by field measurements at the receiver points are given in Appendix A.

Distribution of Background Noise Level in the hall

In Table 4.4, the background values measured at ACC are given according to the frequencies.

Table 4.4 Measured Background Noise Levels at ACC.

	Frequency [Hz]						
	125	250	500	1000	2000	4000	LAeq
Mean	30.4	33.8	37.5	37.5	32.9	24.9	42.6

LA_{eq} value is obtained 42.6 dB by the field measurement.

Distribution of Early Decay Time(EDT) in the hall

In Table 4.5, the EDT values measured at ACC are given according to the frequencies. The results of the measurements made with the Interrupted Method for the purpose of checking the accuracy of the values measured by the Sweep Signal Method are also included in the table.

Table 4.5 Measured EDT Values at ACC.

EDT [s]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	0.91	1.01	0.84	0.90	0.86	0.79
S2	1.63	0.88	1.00	1.07	0.90	0.84
MEAN	1.27	0.94	0.92	0.98	0.88	0.81
Interrupted Method	1.79	0.96	1.03	0.99	0.97	0.84

The graph of the measurement results is given in Figure 4.18.

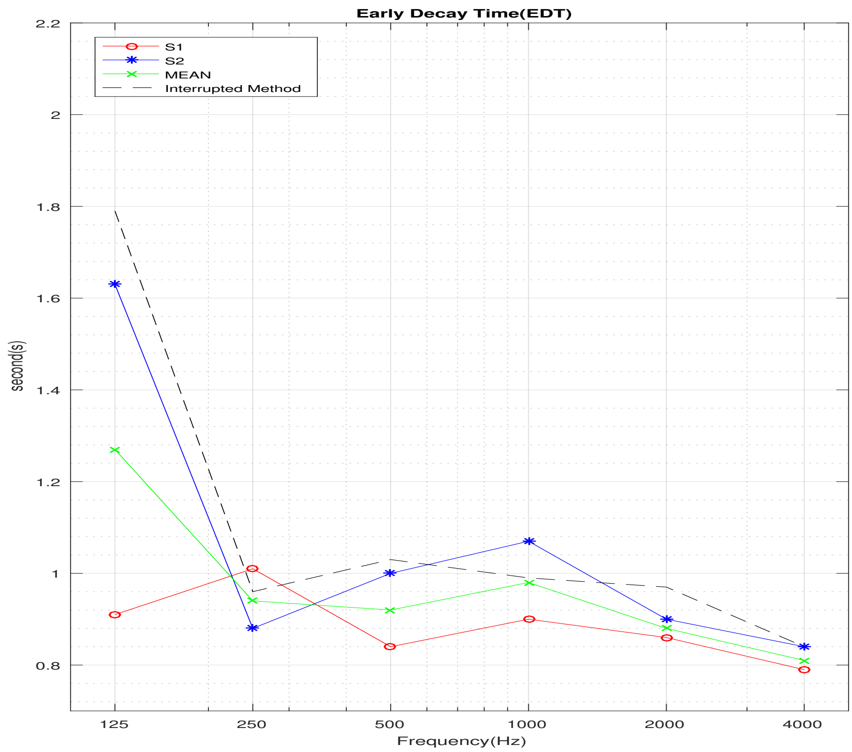

Figure 4.18 Measured EDT Values at ACC.

It shows that the EDT at medium frequencies between 500 and 1000 Hz is 0.95 seconds according to the field measurements. For S2 source position, EDT values are measured higher than S1 source position. Average values obtained at 2000 Hz - 4000 Hz high frequencies are lower than other frequency range values. The EDT values obtained by the interrupted method are consistent with results performed by the Sweep Method except for the 125 Hz frequency value. This indicates that field measurements are reliable.

Distribution of Reverberation Time (RT) in the hall

In Table 4.6, the RT values measured at ACC are given according to the frequencies. The results of the measurements made with the Interrupted Method for the purpose of checking the accuracy of the values measured by the Sweep Signal Method are also included in the table.

Table 4.6 Measured RT Values at ACC.

RT [s]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	1.28	1.05	1.02	0.95	0.87	0.76
S2	1.43	1.09	1.03	0.96	0.93	0.79
MEAN	1.35	1.07	1.02	0.95	0.90	0.77
Interrupted Method	1.44	1.35	0.99	1.01	0.97	0.88

The graph of the measurement results is given in Figure 4.19.

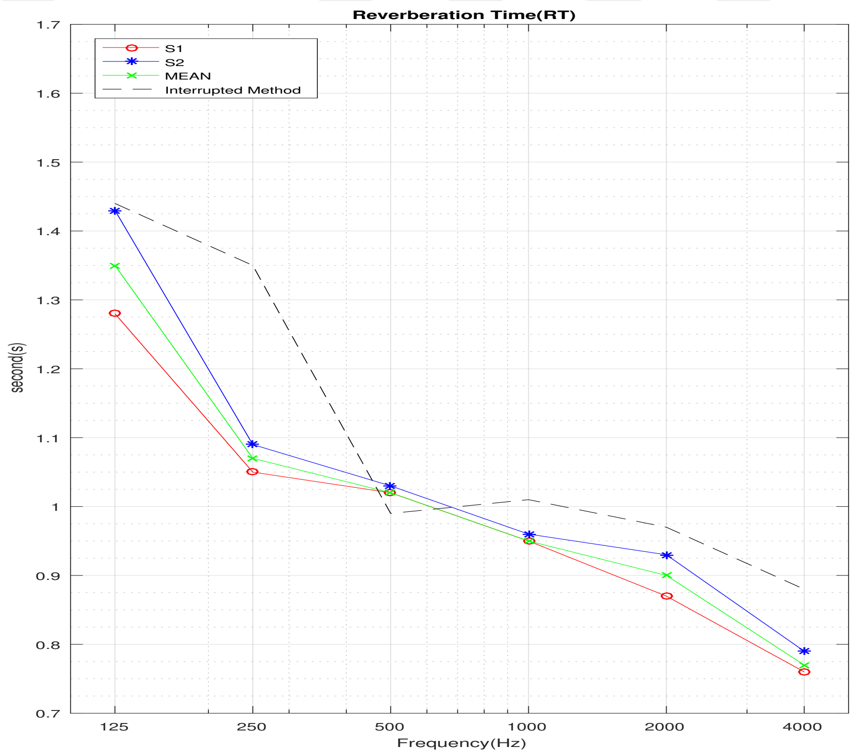

Figure 4.19 Measured RT Values at ACC.

The RT is 1.00 second at mid frequencies according to the field measurement results. As the frequency increases, the reverberation time decreases. The RT values for S2 position are higher than S1 position. The RT values obtained by the interrupted method are consistent with results performed by the Sweep Method.

Distribution of Centre Time (T_s) in the hall

In Table 4.7, the T_s values measured at ACC are given according to the frequencies.

Table 4.7 Measured T_s Values at ACC.

T_s [ms]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	81.58	61.03	46.37	52.20	56.33	54.24
S2	130.33	70.29	56.95	61.49	62.83	51.66
MEAN	105.95	65.66	51.66	56.85	59.58	52.95

The graph of the measurement results is given in Figure 4.20.

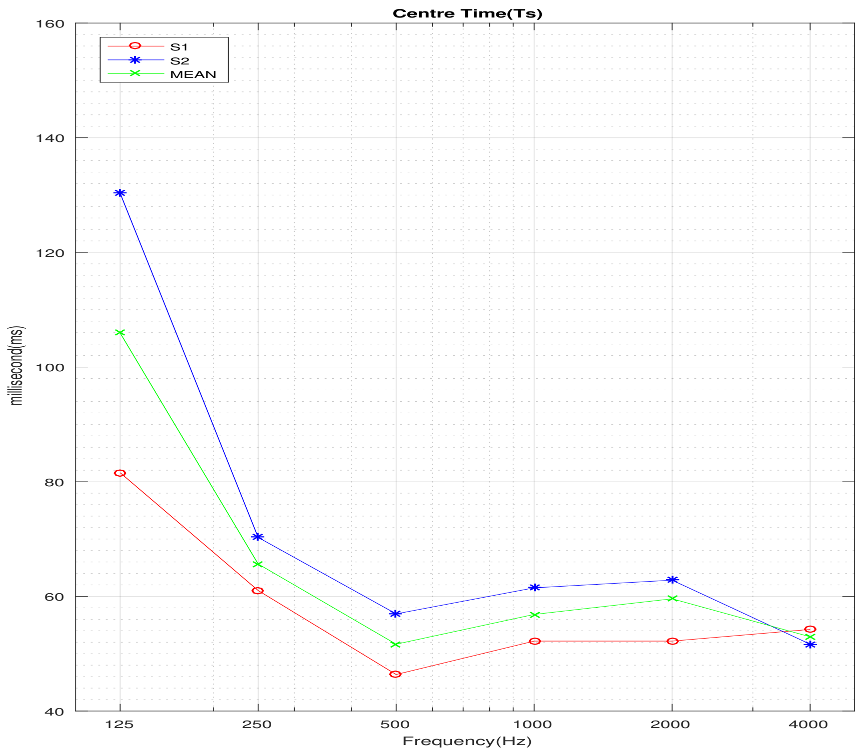

Figure 4.20 Measured T_s Values at ACC.

The results show that T_s at medium frequencies is 54.25 ms. The T_s values measured at medium frequencies are lower than other frequencies results. Especially at 125 Hz, there is a marked difference in T_s values measured according to the source points.

Distribution of Distinctness (D_{50}) in the hall

In Table 4.8, the D_{50} values measured at ACC are given according to the frequencies.

Table 4.8 Measured D_{50} Values at ACC.

D50 [-]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	0.45	0.59	0.62	0.60	0.57	0.57
S2	0.37	0.50	0.65	0.58	0.55	0.63
MEAN	0.41	0.54	0.63	0.59	0.56	0.60

The graph of the measurement results is given in Figure 4.21.

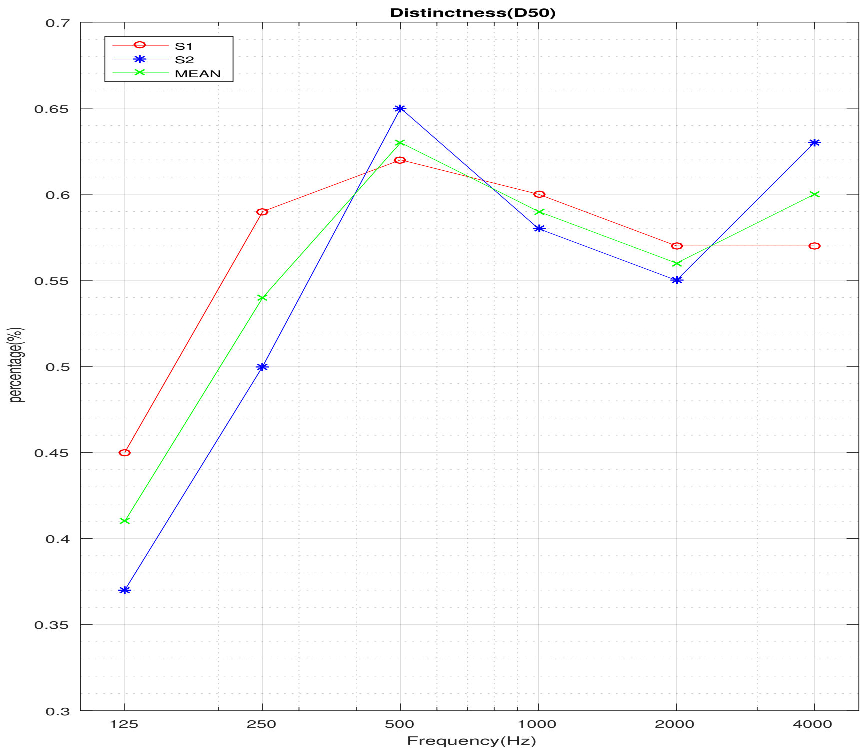

Figure 4.21 Measured D_{50} Values at ACC.

The D_{50} value at medium frequencies is 0.61 according to the field measurement results. As can be seen from the graph, as frequency increases, D_{50} value increases. The maximum value is obtained at 500 Hz and the smallest is at 125

Hz. The measured values for source points S1 and S2 are very close to each other from the medium frequencies to higher ones.

Distribution of Clarity (C_{80}) in the hall

In Table 4.9, the C_{80} values measured at ACC are given according to the frequencies.

Table 4.9 Measured C_{80} Values at ACC.

C80 [dB]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	3.74	5.22	5.68	4.86	4.28	4.61
S2	1.97	4.45	5.34	3.91	4.12	5.14
MEAN	2.85	4.83	5.51	4.39	4.20	4.87

The graph of the measurement results is given in Figure 4.22.

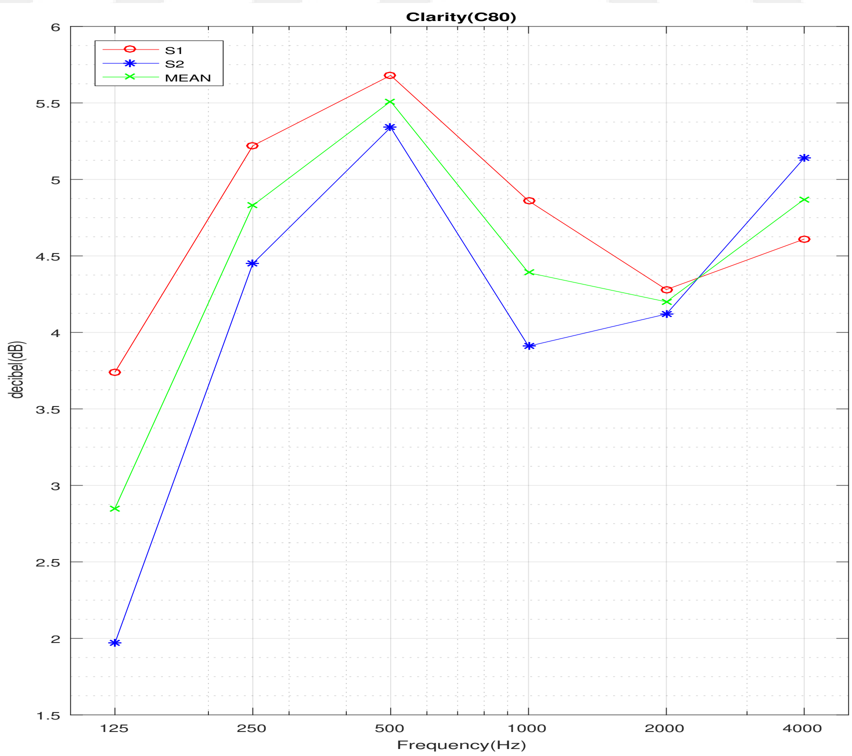

Figure 4.22 Measured C_{80} Values at ACC.

It shows that the C_{80} at medium frequencies between 500 and 1000 Hz is 4.95 dB according to the results. While the C_{80} parameter has the highest value at 500 Hz, it is the smallest at 125 Hz.

Distribution of Speech Transmission Index (STI) in the hall

The STI values measured at ACC are given according to the source positions in Table 4.10.

Table 4.10 Measured STI Values at ACC.

Source	STI	STI-Female	STI-Male
S1	0.64	0.64	0.59
S2	0.62	0.64	0.59
MEAN	0.63	0.64	0.59

According to the results obtained by the field measurements, the STI value is 0.63. While the STI-Female is 0.64, the STI-Male is 0.59.

Field measurement results for the Auditorium

In this section, the average values of the measurement results of 3 source and 16 receiver points in the Auditorium will be shown by tables and graphs. All values measured at the receiver points are given in Appendix B.

Distribution of Background Noise Level in the hall

In Table 4.11, the background values measured at the Auditorium are given according to the frequencies.

Table 4.11 Measured Background Noise Levels at the Auditorium.

	Frequency [Hz]						
	125	250	500	1000	2000	4000	LAeq
Mean	27.04	31.98	38.26	36.16	36.11	31.00	42.73

The Background measurements performed in the auditorium show that the LA_{eq} is 42.7 dB.

Distribution of Early Decay Time (EDT) in the hall

In Table 4.12, the EDT values measured at the Auditorium are given according to the frequencies. The results of the measurements made with the Interrupted Method for the purpose of checking the accuracy of the values measured by the Sweep Signal Method are also included in the table.

Table 4.12 Measured EDT Values at the Auditorium.

EDT [s]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	1.65	1.21	1.25	1.23	1.30	1.06
S2	1.72	1.62	1.50	1.35	1.27	1.11
S3	1.26	1.29	1.39	1.39	1.28	1.08
MEAN	1.54	1.37	1.38	1.32	1.28	1.08
Interrupted Method	1.68	1.23	1.37	1.24	1.14	0.84

The graph of the measurement results is given in Figure 4.23.

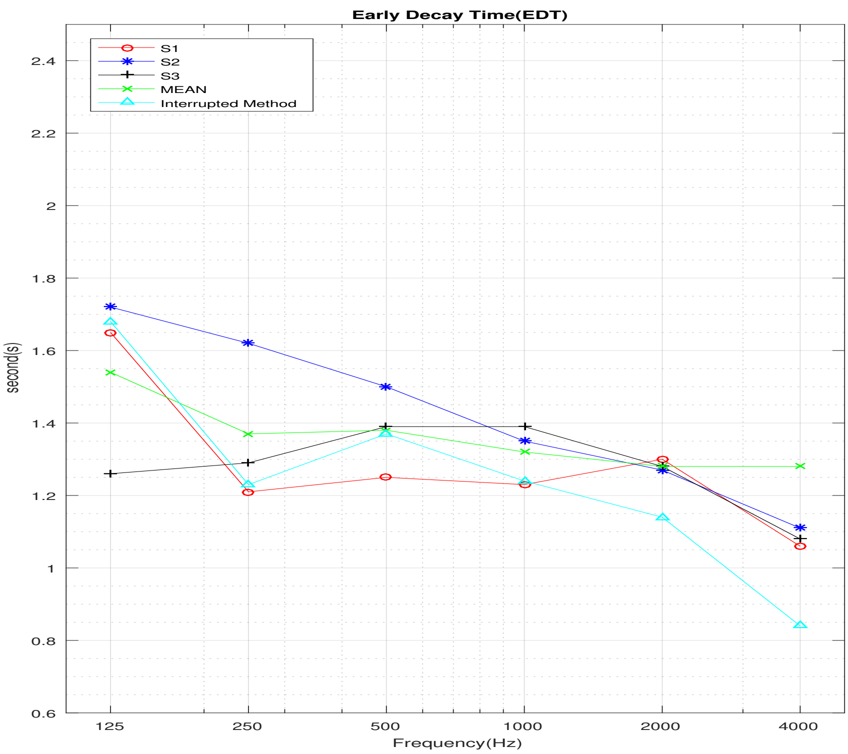

Figure 4.23 Measured EDT Values at the Auditorium.

The EDT is 1.35 seconds at mid frequencies according to the field measurement results. For the source point S2, the EDT values obtained at the low and medium frequencies for this point are higher than the values measured at the other source points. In general, it is seen that the EDT value decreases as you go from low frequencies to high frequencies. The EDT values obtained by the interrupted method are consistent with results performed by the Sweep Method. This indicates that field measurements are reliable.

Distribution of Reverberation Time (RT) in the hall

In Table 4.13, the RT values measured at the Auditorium are given according to the frequencies. The results of the measurements made with the Interrupted Method for the purpose of checking the accuracy of the values measured by the Sweep Signal Method are also included in the table.

Table 4.13 Measured RT Values at the Auditorium.

RT [s]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	2.12	1.70	1.52	1.30	1.13	0.98
S2	1.72	1.64	1.41	1.20	1.04	0.77
S3	1.93	1.59	1.55	1.35	1.17	1.01
MEAN	1.92	1.64	1.49	1.28	1.11	0.92
Interrupted Method	1.59	1.41	1.70	1.46	1.23	0.99

The graph of the measurement results is given in Figure 4.24.

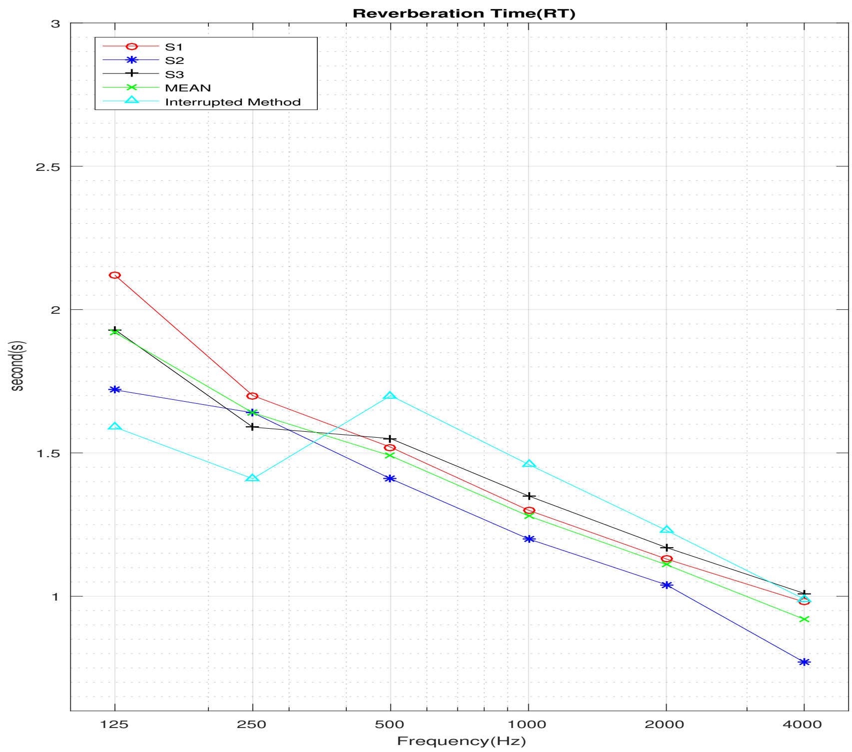

Figure 4.24 Measured RT Values at the Auditorium.

The RT value at medium frequencies is 1.38 seconds according to the field measurement results. The rise at the S1 source, especially at 125 Hz, is quite clear. The graph shows that as the frequency increases, the RT values decrease.

Distribution of Centre Time (T_s) in the hall

In Table 4.14, the Ts values measured at the Auditorium are given according to the frequencies.

Table 4.14 Measured T_s Values at the Auditorium.

T_s [ms]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	99.89	80.66	77.18	92.33	78.72	75.89
S2	131.62	88.62	75.49	96.33	80.49	75.53
S3	76.68	75.74	60.41	79.16	82.85	79.78
MEAN	102.73	81.67	71.03	89.27	80.69	77.07

The graph of the measurement results is given in Figure 4.25.

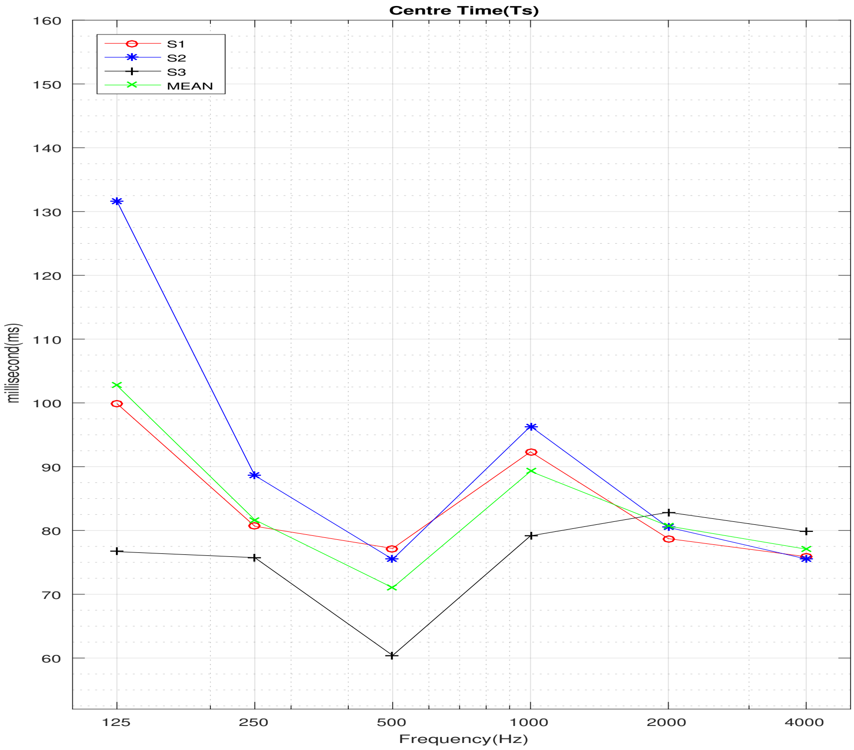

Figure 4.25 Measured T_s Values at the Auditorium.

It shows that the T_s at medium frequencies between 500 and 1000 Hz is 80.15 ms according to the results. The high value at the S2 source point is remarkable. The lowest value is obtained at 500 Hz. While the mean values tended to decrease between 125 and 500 Hz, a rise from 1000 Hz is observed.

Distribution of Distinctness (D_{50}) in the hall

In Table 4.15, the D_{50} values measured at the Auditorium are given according to the frequencies.

Table 4.15 Measured D_{50} Values at the Auditorium.

D_{50} [-]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	0.47	0.42	0.41	0.33	0.41	0.39
S2	0.38	0.51	0.52	0.36	0.43	0.45
S3	0.56	0.55	0.56	0.45	0.41	0.43
MEAN	0.47	0.49	0.50	0.38	0.42	0.42

The graph of the measurement results is given in Figure 4.26.

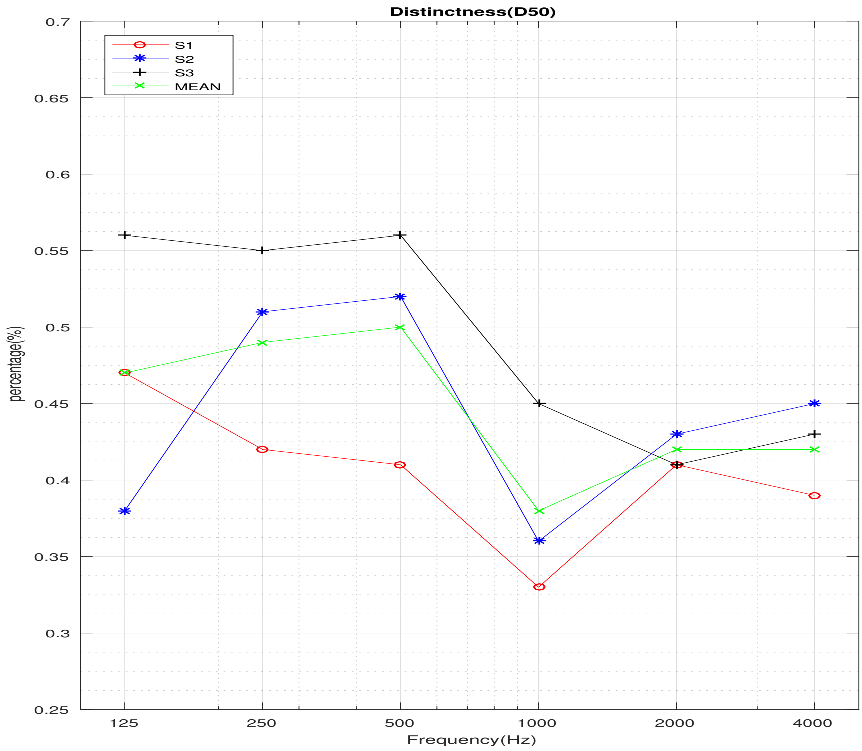

Figure 4.26 Measured D_{50} Values at the Auditorium.

The D_{50} value at medium frequencies is 0.44 according to the field measurement results. The highest value of D_{50} is obtained at 500 Hz. While the value of D_{50} increases at 125 Hz - 500 Hz, a decrease at 1000 Hz is observed and the D_{50} values increases at 1000 Hz - 4000 Hz.

Distribution of Clarity (C_{80}) in the hall

In Table 4.16, the C_{80} values measured at the Auditorium are given according to the frequencies.

Table 4.16 Measured C_{80} Values at the Auditorium.

C_{80} [dB]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	3.50	2.46	1.92	0.75	1.65	2.43
S2	-0.10	1.83	2.35	0.67	1.80	2.46
S3	2.87	3.56	3.83	2.09	1.79	2.77
MEAN	2.09	2.62	2.70	1.17	1.75	2.55

The graph of the measurement results is given in Figure 4.27.

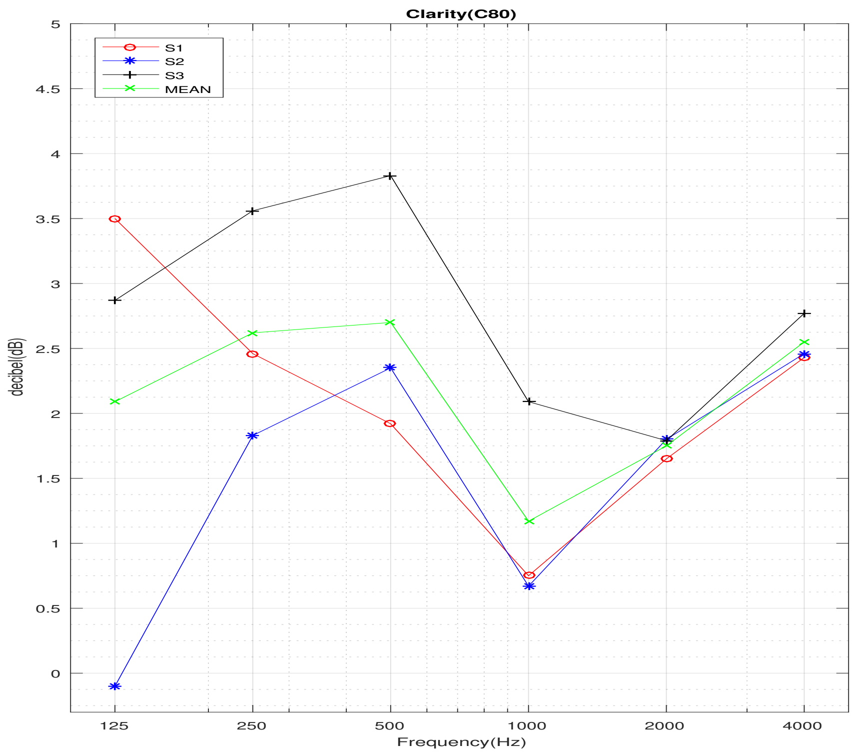

Figure 4.27 Measured C_{80} Values at the Auditorium.

The C_{80} is 1.93 dB at mid frequencies according to the field measurement results. The value of -0.1 dB obtained at 125 Hz at the measurement performed at the S2 source point did not escape attention. The values in the range of 125 Hz - 500 Hz at the S3 source point are well above the mean values.

Distribution of Speech Transmission Index (STI) in the hall

In Table 4.17, the STI values measured at the Auditorium are given according to the source positions.

Table 4.17 Measured STI Values at the Auditorium.

Source	STI	STI-Female	STI-Male
S1	0.54	0.52	0.48
S2	0.53	0.52	0.48
S3	0.56	0.53	0.49
MEAN	0.54	0.52	0.48

According to the results obtained in the field measurements, the STI value is 0.54. The STI-Female value is 0.52, while the STI-Male value is 0.48.

4.3 Computer Simulation

In pursuit of the field measurements in order to examine the general situation in the selected halls, the acoustic parameter values were examined by using Odeon software after the three dimensional designs of these halls were sketched. The purpose of this is to compare the parameter values obtained by the field measurements and simulation results.

Before commenting the halls for room acoustics, the field measurement values were compared with the ODEON values and models were calibrated based on the measured values.

Because of the difficulties in the accurate prediction of the absorption coefficients of the materials in the halls examined in this thesis, error rates of up to 10 percent can be accepted when the field measurement results and the acoustic analyzes performed in the simulation results are evaluated.

4.3.1 Process of Acoustic Analysis on Simulation Program

Models, sketched in SketchUp 16.1 program, were transferred to acoustic simulation program. For the acoustic calculations, ODEON13 Combined Room Acoustics Program, which was prepared by experts of the Acoustic Department of the Technical University of Denmark and proved scientific accuracy, was used.

The model is sketched roughly as suggested in the program, with details such as decorations in the hall being ignored. Moreover, since the program works on planar surfaces and the number of surfaces affects the duration of the simulation, curvilinear surfaces are formed from broken surfaces and surfaces with different materials are defined with different layers.

First of all, the 3D Geometry Debugger command has been tested to see if there are superimposed surfaces in the loaded models in the ODEON program. The surfaces defined by the 3D surface elements were assigned to 20% absorbency and models were inspected using the 3D Investigate Rays button to see if the rays had escaped.

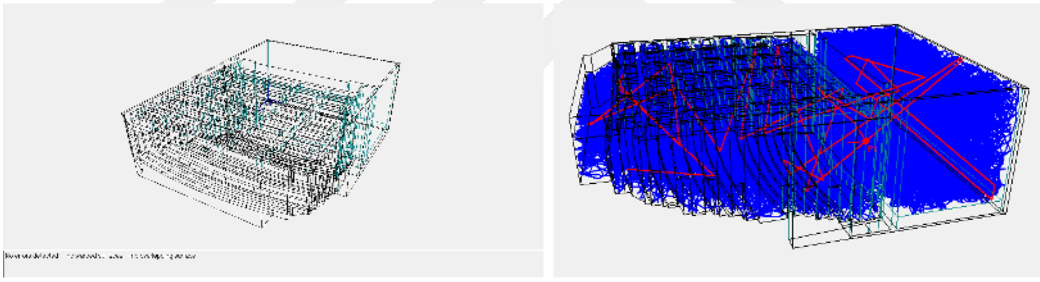

Figure 4.28 Suitability Tests of ACC for Simulation.

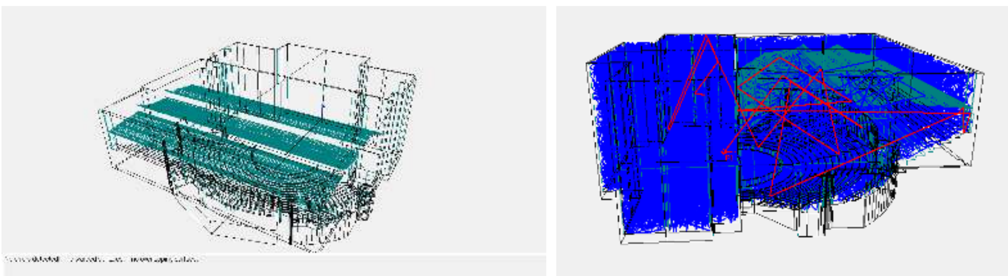

Figure 4.29 Suitability Tests of the Auditorium for Simulation

After checking the models, the second step is to set the calculation parameters to be used in the models transferred to ODEON Acoustic Simulation Program. Room set up parameters are given, respectively.

i. Impulse response length: It is the time interval between the rays emitted from the source and then completely absorbed. In order to obtain healthy results, at least 2/3 of the reverberation time should be taken [41].

ii. Number of late rays: The Number of Late Rays determines density of reflections in the late part of the decay [41]. The studies were based on 'engineering' point signal parameter and 'lambert' scattering method.

iii. Maximum reflection order: A parameter that specifies the reflection numbers of rays after they hit a surface [41]. 2000 number of reflections were used in the studies, as suggested by ODEON.

iv. Impulse response resolution: It is the width of the time steps in the Impulse response histogram in which the energy of the reflections are collected during a point response calculation. This is used in the calculation of EDT and T30. The recommended value is 3 ms [41].

v. Transition order: This is used to calculate the energy of the first reflections. In this work, the TO = 2 is used, as suggested by ODEON [41].

vi. Number of early rays: ODEON will estimate a Number of early rays to use in order to detect important early reflections based on the number and size of surfaces, the dimensions of the room as well as the user defined Transition order. The Number of early rays is normally best left for ODEON to decide [41].

vii. Number of early scatter rays (per image source): If the number of rays scattered according to the scientific surveys is larger than 0, the sound rays hit the surfaces and the early reflections are scattered in different directions. This scattering is up to the scattering coefficient given. The recommended value is 100 [41].

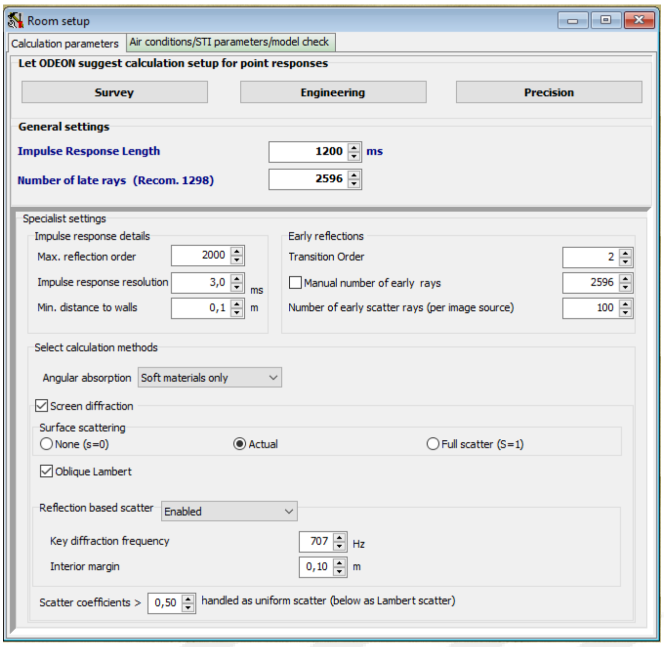

Figure 4.30 Room Set up Parameters Used in ODEON for ACC.

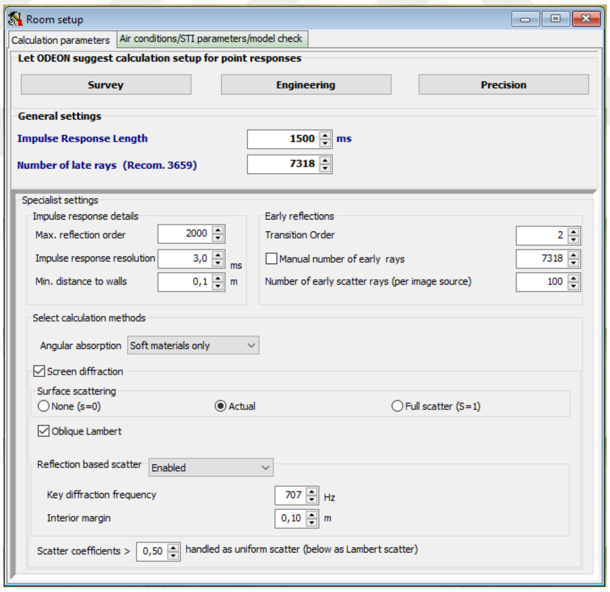

Figure 4.31 Room Set up Parameters Used in ODEON for the Auditorium.

viii. Background noise levels: This parameter is used to define the existing background in dB. This is especially used to find the Speech Transmission Index [41].

ix. Temperature and humidity: These parameters are used to define the existing halls' temperature and humidity values. The values to be entered into the

ODEON were determined by the temperature and humidity measurements performed in the halls to be analyzed.

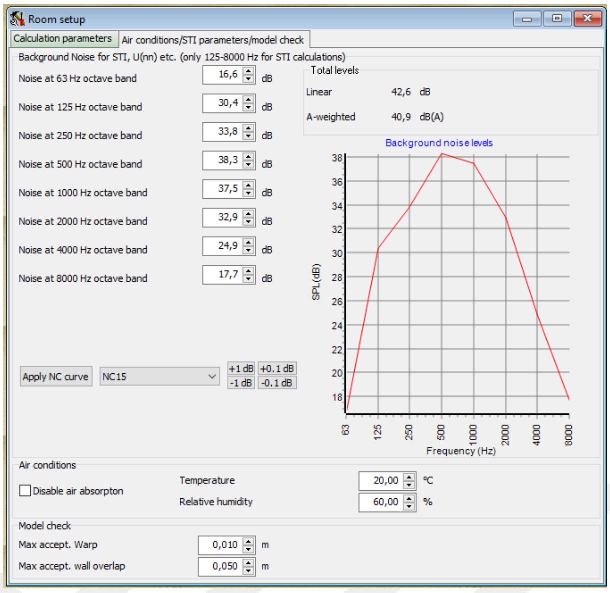

Figure 4.32 The Background Noises, Temperature and Humidity Values Used in ODEON for ACC.

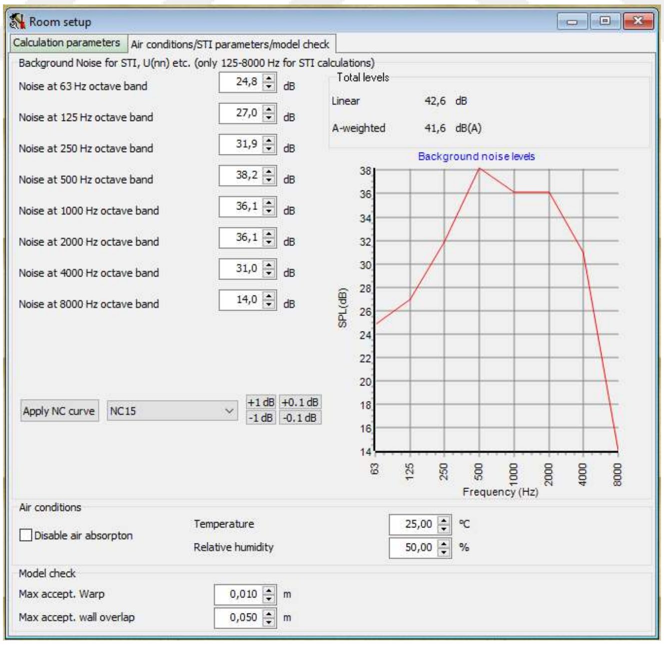

Figure 4.33 The Background Noises, Temperature and Humidity Values Used in ODEON for the Auditorium.

The third important decision is the correct identification of the absorptive and scattering coefficients given to the surfaces. The energy of early reflections in the sound field of a room depends directly on the geometry of the hall and on the absorptive and scattering properties of the surfaces that define it. For this reason, in order to obtain reliably results with respect to the halls to be simulated, the surfaces constituting the hall geometry should be assigned appropriate materials for their actual conditions.

After the calculation parameters to be used in the models are defined, the desired materials are assigned to all the surfaces by entering the "Set Materials" section.

Material assignment was made by using material library in ODEON Acoustic Simulation Program, catalogs of company producing acoustic materials and material absorption coefficients in the literature. The list of materials assigned to ACC and the absorption and scattering coefficients of these materials shown in Table 4.18 and Table 4.19, respectively.

Table 4.18 ACC Material List.

Material #	Material name
3020	16.22 *mm* wood facing frame over 50 *mm* cavity filled with mineral wool
4040	Plasterboard on frame, 9.5 *mm* boards, 100 *mm* empty cavity
7000	Needle felt 5 *mm* stuck to concrete
7004	Carpet heavy, on concrete
8005	Cotton curtains draped to 3/4 area approx. 130 *mm* from wall
11009	Audience, lightly upholstered seats
3004	Wooden floor on joists

Table 4.19 Absorption (α) and Scattering (δ) Coefficients of Materials Used for ACC in ODEON.

Material #	63	125	250	500	1000	2000	4000	8000	α	δ
3020	0.30	0.31	0.22	0.13	0.10	0.08	0.09	0.10	0.1 (L)	0.05
4040	0.11	0.14	0.18	0.08	0.04	0.03	0.02	0.02	0.05(L)	0.05
7000	0.02	0.02	0.02	0.05	0.23	0.35	0.37	0.51	0.15(H)	0.05
7004	0.02	0.03	0.05	0.15	0.35	0.75	0.74	0.74	0.25(H)	0.05
8005	0.39	0.21	0.61	0.81	0.59	0.44	0.58	0.68	0.5(LM)	0.05
11009	0.65	0.73	0.58	0.69	0.75	0.80	0.75	0.74	0.75	0.6
3004	0.23	0.09	0.09	0.14	0.03	0.04	0.04	0.03	0.05(L)	0.05

The list of materials assigned to the Auditorium of the Gaziantep University and the absorption and scattering coefficients of these materials shown in Table 4.20 and Table 4.21, respectively.

Table 4.20 Auditorium Material List.

Material #	Material name
15100	Gustafs, PD8 Domino perforation 8 mm, open area 24 %
11008	Audience, medium upholstered seats
10007	Solid wooden door
8200	Gerriets GmbH, GERRA CS
7005	Carpet heavy, on hairfelt or foam rubber
3100	Gustafs MDF-panel system
3021	6 mm wood fibre board on laths, cavity > 100 mm deep
3020	16.22 mm wood facing on frame over 50 mm cavity filled with mineral wool
3004	Wooden floor on joists
100	Rough concrete

Table 4.21 Absorption (α) and Scattering (δ) Coefficients of Materials Used for Auditorium in ODEON.

Material #	63	125	250	500	1000	2000	4000	8000	α	δ
15100	0.33	0.18	0.95	0.74	0.81	0.05	0.64	0.02	0.15	0.05
11008	0.98	0.78	0.33	0.31	0.09	0.46	0.27	0.48	0.2(LM)	0.6
10007	0.03	0.04	0.05	0.06	0.13	0.09	0.08	0.18	0.1	0.05
8200	0.26	0.24	0.40	0.42	0.38	0.55	0.41	0.46	0.45	0.05
7005	0.24	0.03	0.03	0.71	0.77	0.14	0.77	0.14	0.2	0.05
3100	0.20	0.06	0.19	0.20	0.10	0.34	0.15	0.05	0.2	0.05
3021	0.42	0.06	0.40	0.23	0.40	0.26	0.36	0.14	0.25(L)	0.05
3020	0.21	0.13	0.03	0.05	0.07	0.43	0.04	0.43	0.1(H)	0.05
3004	0.55	0.30	0.04	0.36	0.09	0.05	0.05	0.05	0.1(M)	0.05
100	0.03	0.35	0.21	0.05	0.52	0.68	0.59	0.85	0.15	0.05

Another important decision is place the sources and receivers at the actual measurement points as described in Chapter 4.2.2, by using 'Source and Receivers' section in ODEON. The chosen sound source type is point source that emits pink noise and does not change with respect to frequencies.

The locations of the source points in the simulation program are given in Fig 4.34 and Fig 4.35.

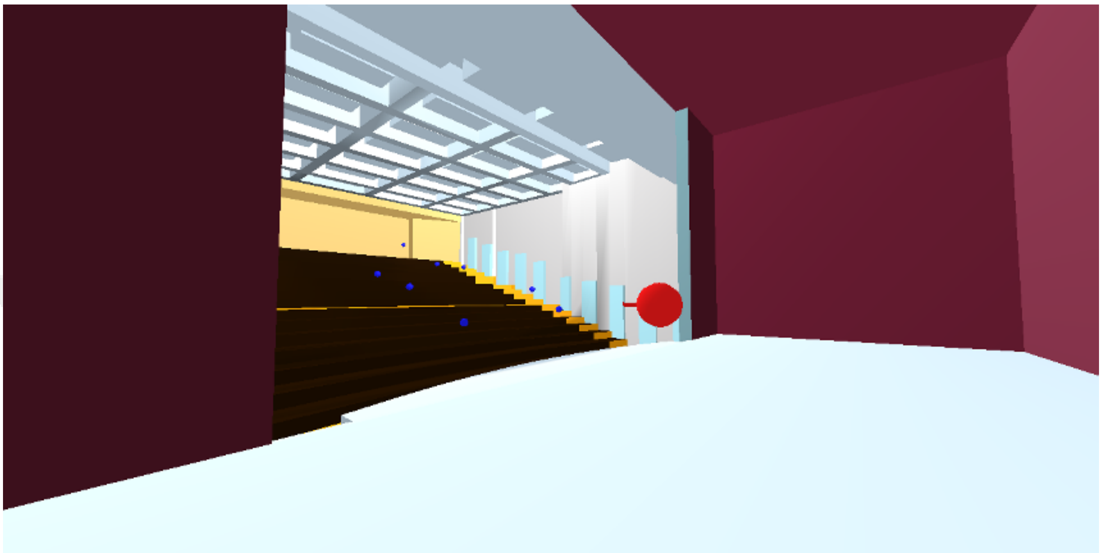

Figure 4.34 The Location of the Source Point of ACC in ODEON.

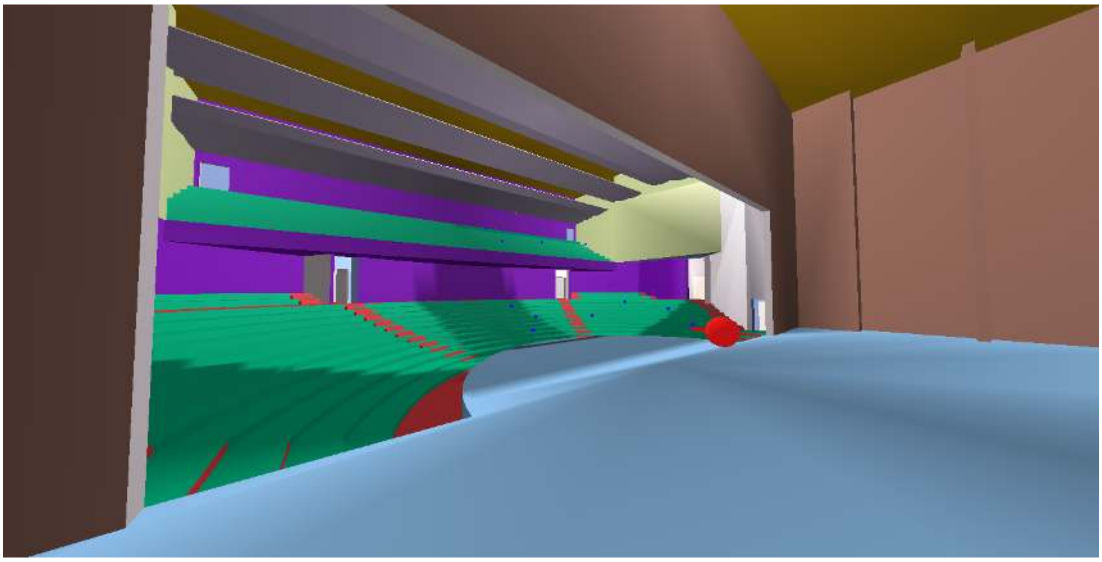

Figure 4.35 The Location of the Source Point of the Auditorium in ODEON.

In order to ensure that the acoustic parameters calculated at the receiver points are close to the true, the definitions given for the receivers of the ISO 3382-1 standard followed in the measurement methods used for the detection of the real condition have been met.

The locations of the receiver points in the simulation program are given in Fig 4.36 and Fig 4.37.

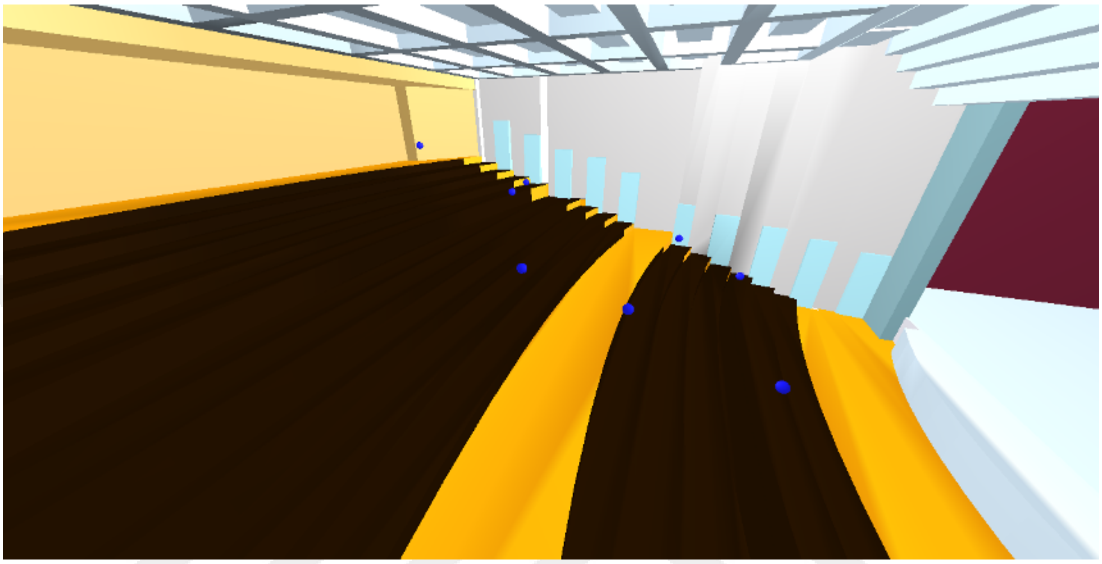

Figure 4.36 The Locations of the Receiver Points of ACC in ODEON.

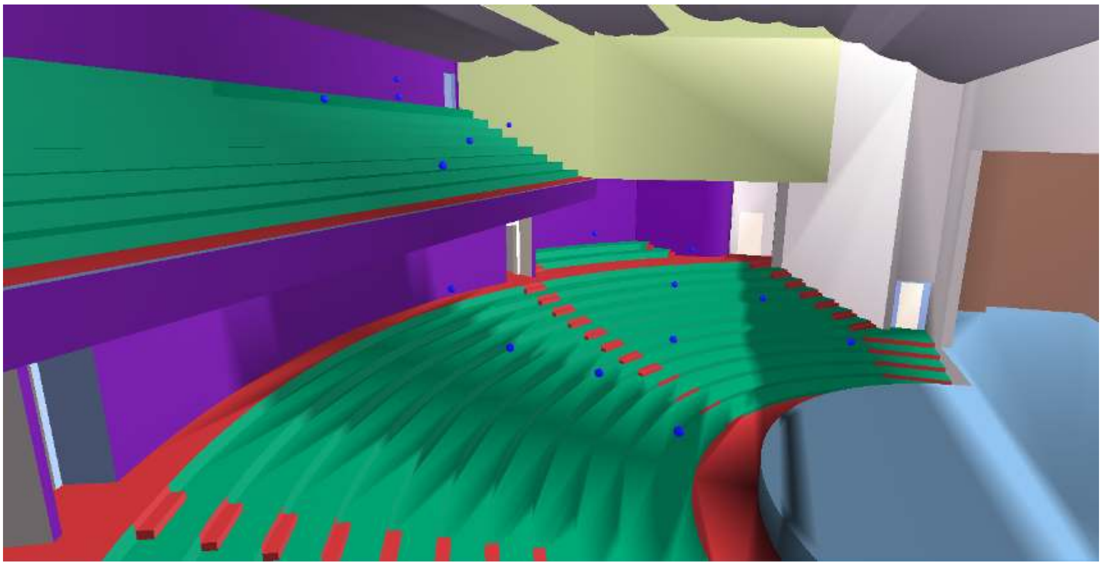

Figure 4.37 The Locations of the Receiver Points of the Auditorium in ODEON.

4.3.2 Results of Simulation

As the case with field measurements, the results of the objective parameter values, calculated by simulations, were obtained for frequency values between 125 Hz and 4000 Hz.

Simulation results for Atatürk Cultural Center

In this section, the average values of the simulation results of 2 source and 8 receiver points in ACC will be shown by tables and graphs. All values obtained by simulation at the receiver points are given in Appendix C.

Distribution of Early Decay Time(EDT) in the hall

The EDT values simulated for ACC are given according to the frequencies in Table 4.22.

Table 4.22 Simulated Results of EDT Values for ACC.

EDT [s]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	1.40	1.07	0.86	0.96	0.89	0.75
S2	1.50	1.18	1.13	1.08	1.03	0.87
MEAN	1.45	1.12	0.99	1.02	0.96	0.81

The graph of the simulation results is given in Figure 4.38.

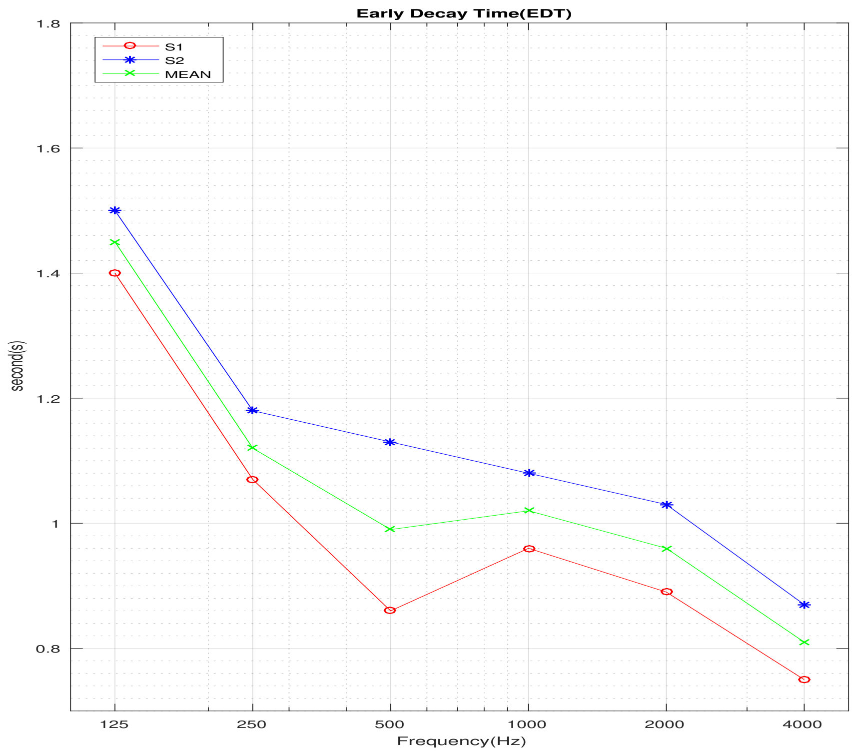

Figure 4.38 Simulated Results of EDT Values for ACC.

It shows that the EDT at medium frequencies between 500 and 1000 Hz is 1.00 second according to the results. The lowest EDT values are measured at 125 Hz. The second source position has the highest value in the frequency range and the EDT decreases as the frequency increases.

Distribution of Reverberation Time (RT) in the hall

In Table 4.23, the RT values simulated for ACC are given according to the frequencies.

Table 4.23 Simulated Results of RT Values for ACC.

RT [s]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	1.27	1.07	0.87	0.94	0.85	0.76
S2	1.36	1.01	0.90	0.93	0.90	0.79
MEAN	1.31	1.04	0.88	0.93	0.87	0.77

The graph of the simulation results is given in Figure 4.39.

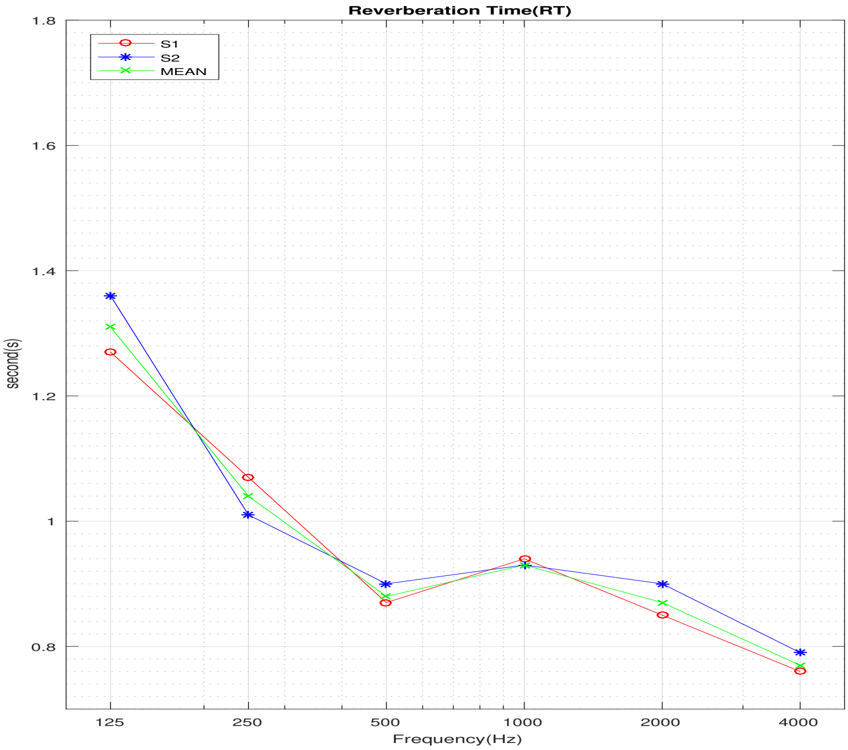

Figure 4.39 Simulated Results of RT Values for ACC.

RT is 0.9 second at mid frequencies according to the simulation results. The reverberation time decreases as the frequency increases. The values obtained at low frequencies are higher than values obtained at medium and high frequencies.

Distribution of Centre Time (T_s) in the hall

In Table 4.24, the T_s values simulated for ACC are given according to the frequencies.

Table 4.24 Simulated Results of T_s Values for ACC.

T_s [ms]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	91	68	53	60	56	46
S2	104	64	55	59	58	47
MEAN	97.5	66	54	59.5	57	46.5

The graph of the simulation results is given in Figure 4.40.

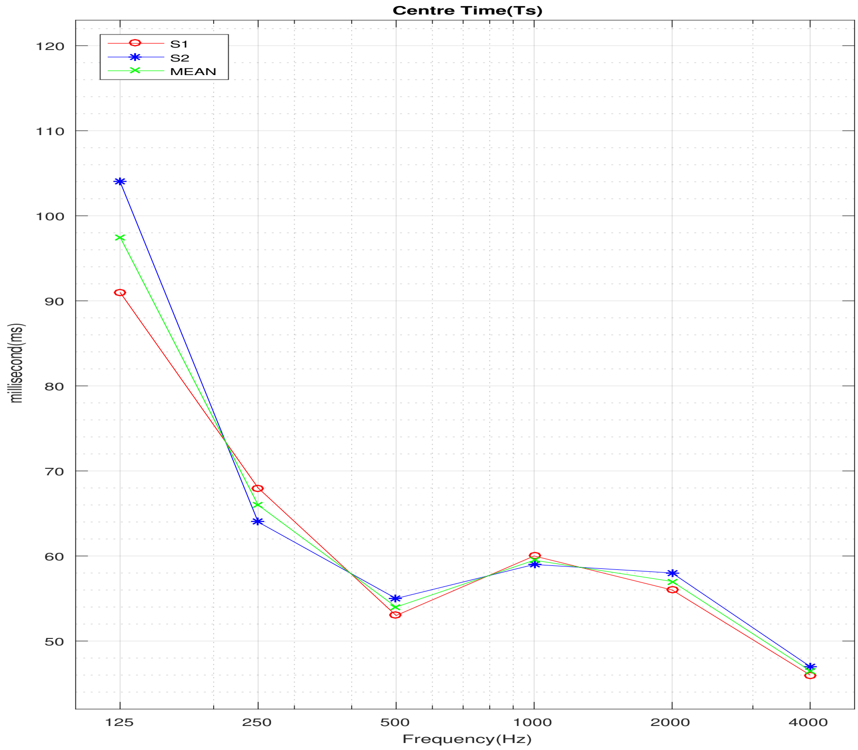

Figure 4.40 Simulated Results of T_s Values for ACC.

The results show that T_s at medium frequencies is 56.75 ms. In particular, there is a marked difference in the T_s values measured at 125 Hz, while at other frequency intervals the T_s values are almost the same for all sources.

Distribution of Distinctness (D_{50}) in the hall

In Table 4.25, the D_{50} values simulated for ACC are given according to the frequencies.

Table 4.25 Simulated Results of D_{50} Values for ACC.

D_{50} [-]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	0.47	0.57	0.65	0.61	0.63	0.68
S2	0.39	0.57	0.64	0.60	0.59	0.66
MEAN	0.43	0.57	0.64	0.60	0.61	0.67

The graph of the simulation results is given in Figure 4.41.

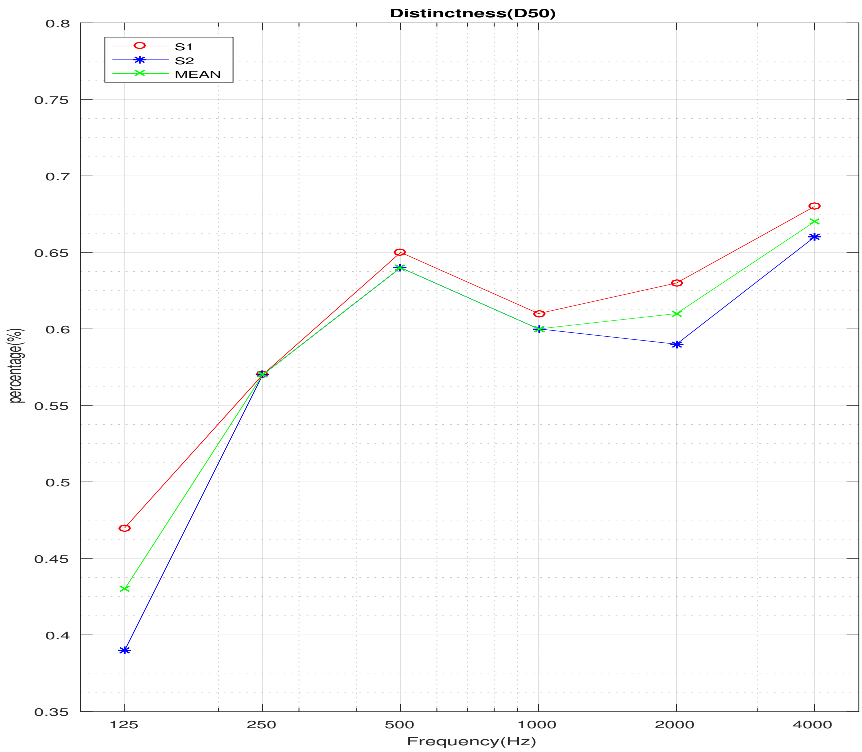

Figure 4.41 Simulated Results of D_{50} Values for ACC.

The D_{50} value at medium frequencies is 0.62 according to the simulation results. The value obtained at 125 Hz is lower than the values obtained at other frequencies. Almost the same results were obtained at 1000 and 2000 Hz.

Distribution of Clarity (C_{80}) in the hall

In Table 4.26, the C_{80} values simulated for ACC are given according to the frequencies.

Table 4.26 Simulated Results of C_{80} Values for ACC.

C_{80} [dB]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	1.7	3.8	5.5	4.6	5.1	6.5
S2	0.1	3.4	4.5	4.1	4.2	5.8
MEAN	0.9	3.6	5.0	4.35	4.65	6.15

The graph of the simulation results is given in Figure 4.42.

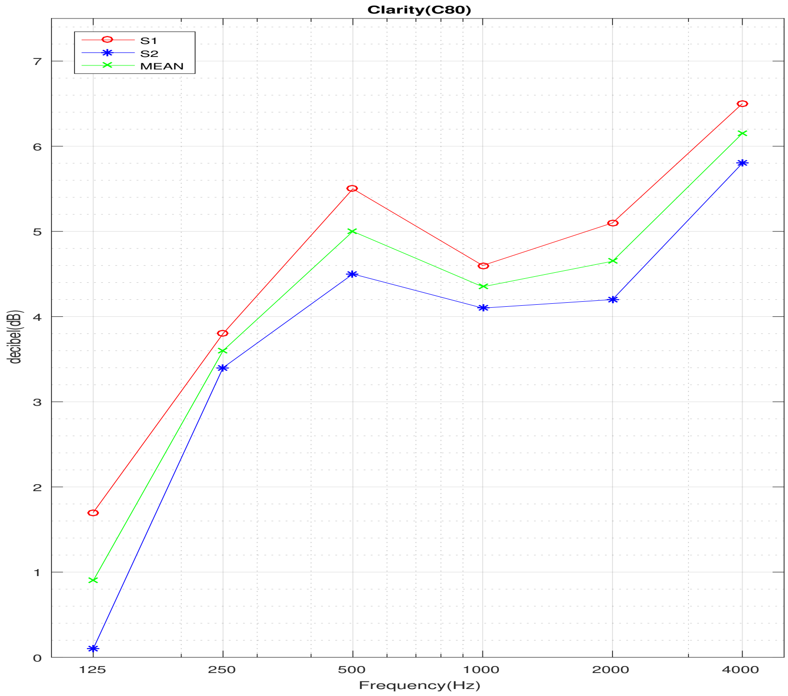

Figure 4.42 Simulated Results of C_{80} Values for ACC.

It shows that the C_{80} at medium frequencies between 500 and 1000 Hz is 4.67 dB according to the results. Especially at 4000 Hz, a very high clarity value is obtained, whereas at 125 Hz, a very low C_{80} value is obtained compared to other frequencies.

Distribution of Speech Transmission Index (STI) in the hall

The STI values simulated for ACC are given according to the source positions in Table 4.27.

Table 4.27 Simulated Results of STI Values for ACC.

Source	STI	STI-Female	STI-Male
S1	0.57	0.58	0.55
S2	0.56	0.57	0.53
MEAN	0.56	0.57	0.54

According to the results obtained by the simulation, the STI value is 0.56. While the STI-Female is 0.57, the STI-Male is 0.54.

Simulation Results for the Auditorium

In this section, the average values of the simulation results of 3 source and 16 receiver points in the Auditorium will be shown by tables and graphs. All values measured at the receiver points are given in Appendix D.

Distribution of Early Decay Time (EDT) in the hall

The EDT values simulated for the Auditorium are given according to the frequencies in Table 4.28.

Table 4.28 Simulated Results of EDT Values for the Auditorium.

EDT [s]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	1.75	1.47	1.52	1.47	1.27	1.18
S2	1.89	1.54	1.54	1.42	1.28	1.15
S3	1.86	1.53	1.54	1.44	1.30	1.19
MEAN	1.83	1.51	1.53	1.44	1.28	1.17

The graph of the simulation results is given in Figure 4.43.

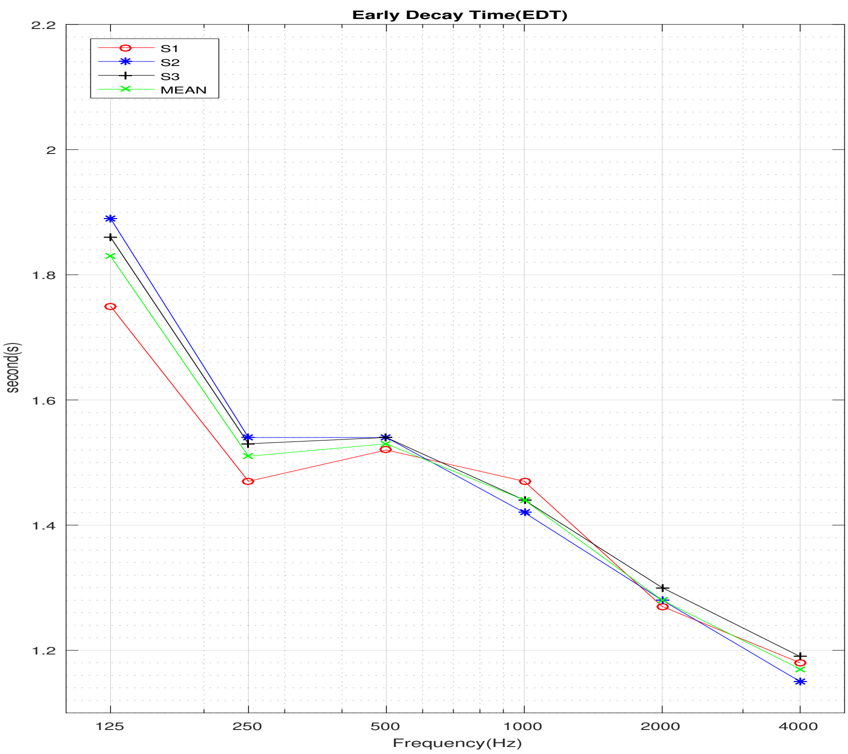

Figure 4.43 Simulated Results of EDT Values for the Auditorium.

The EDT is 1.48 seconds at mid frequencies according to the simulation results. As the frequency increased, a decrease in EDT values is observed. Almost the same results were obtained for each source point.

Distribution of Reverberation Time (RT) in the hall

The RT values simulated for the Auditorium are given according to the frequencies in Table 4.29.

Table 4.29 Simulated Results of RT Values for the Auditorium.

RT [s]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	1.77	1.70	1.50	1.41	1.18	1.16
S2	1.74	1.67	1.45	1.36	1.19	1.14
S3	1.74	1.62	1.43	1.36	1.22	1.13
MEAN	1.75	1.66	1.46	1.37	1.19	1.14

The graph of the simulation results is given in Figure 4.44.

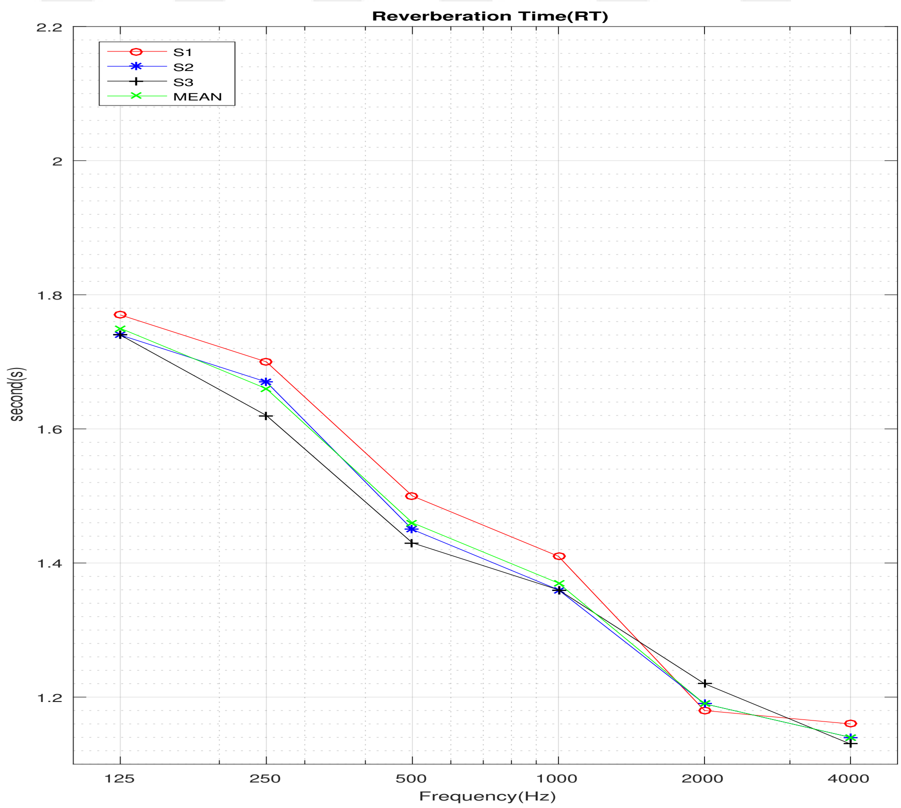

Figure 4.44 Simulated Results of RT Values for the Auditorium.

The RT value at medium frequencies is 1.41 seconds according to the simulation. As seen in the EDT results, it is observed that as the frequency increases, the reverberation time decreases. The values obtained in the first sound position are higher than in other sources.

Distribution of Centre Time (T_s) in the hall

In Table 4.30, the T_s values simulated for the Auditorium are given according to the frequencies.

Table 4.30 Simulated Results of T_s Values for the Auditorium.

T_s [ms]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	96	73	76	73	62	55
S2	105	80	79	73	61	52
S3	87	66	70	69	59	54
MEAN	96	73	75	71.66	60.66	53.66

The graph of the simulation results is given in Figure 4.45.

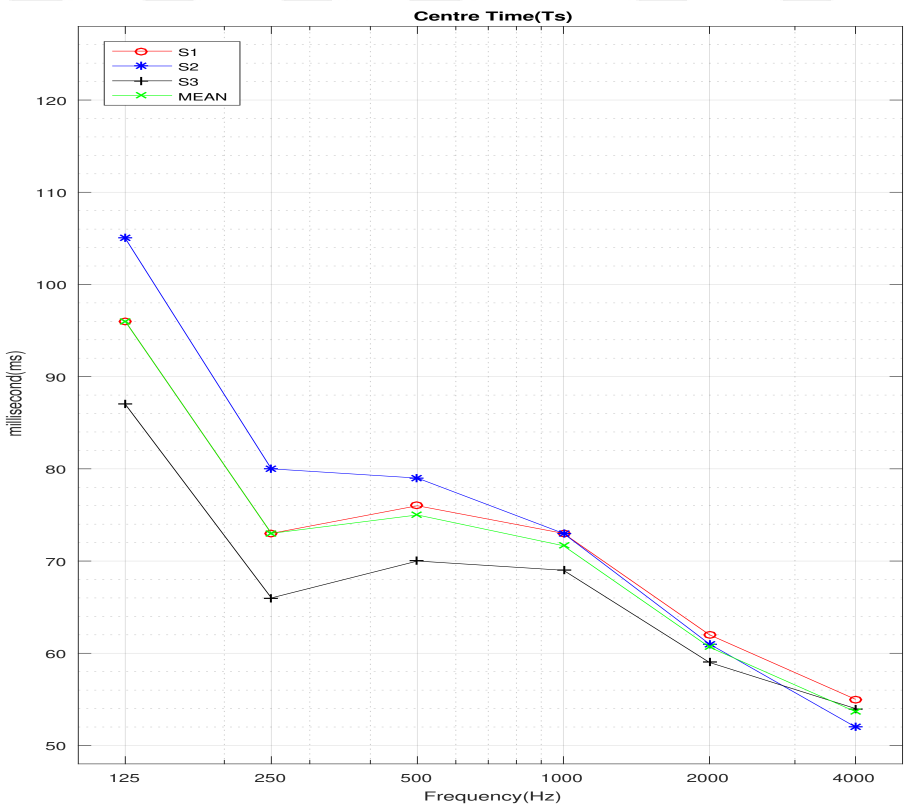

Figure 4.45 Simulated Results of T_s Values for the Auditorium.

It shows that the T_s at medium frequencies between 500 and 1000 Hz is 73.33 ms according to the results. When the Center Time parameter tends to decrease from 125 Hz to 250 Hz, almost the same result is obtained at 500 Hz and a decrease in T_s values is observed as the frequency increases.

Distribution of Distinctness (D_{50}) in the hall

The D_{50} values simulated for the Auditorium are given according to the frequencies in Table 4.31.

Table 4.31 Simulated Results of D_{50} Values for the Auditorium.

D_{50} [-]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	0.49	0.58	0.56	0.57	0.61	0.64
S2	0.44	0.53	0.54	0.55	0.6	0.64
S3	0.57	0.65	0.62	0.61	0.66	0.68
MEAN	0.50	0.58	0.57	0.57	0.62	0.65

The graph of the simulation results is given in Figure 4.46.

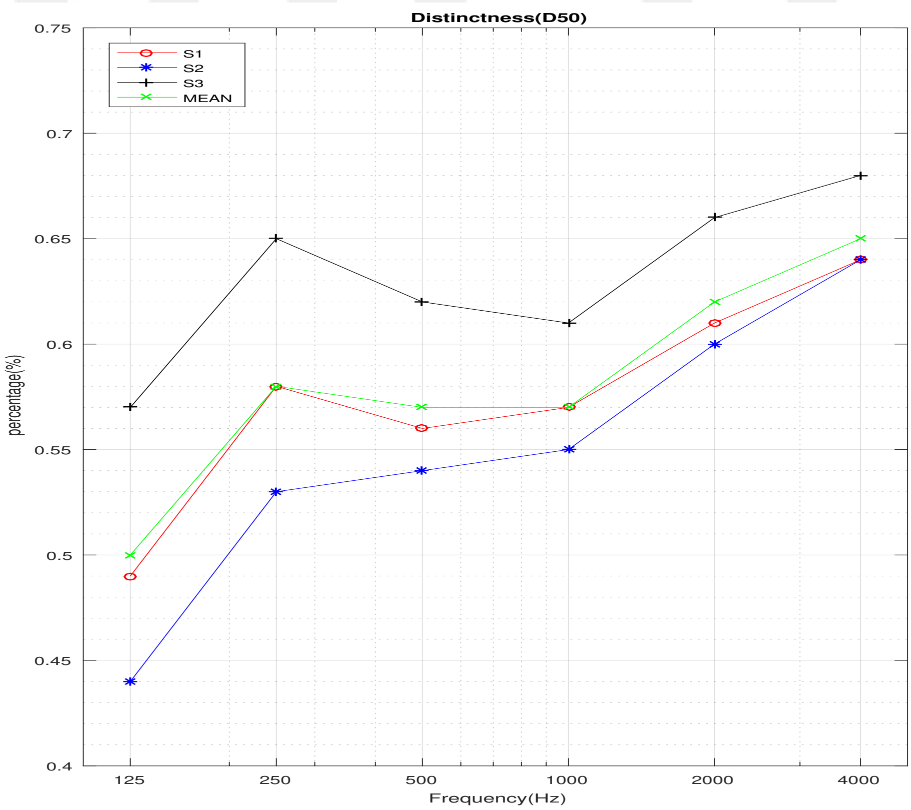

Figure 4.46 Simulated Results of D_{50} Values for the Auditorium.

The D_{50} value at medium frequencies is 0.57. The highest D_{50} values were obtained at the third source position. The values obtained at the 1st and 2nd source points are very close to each other.

Distribution of Clarity (C_{80}) in the hall

In Table 4.32, the C_{80} values simulated for the Auditorium are given according to the frequencies.

Table 4.32 Simulated Results of C_{80} Values for the Auditorium.

C_{80} [dB]	Frequency [Hz]					
Source	125	250	500	1000	2000	4000
S1	1.5	3.1	2.8	2.9	3.9	4.5
S2	1.4	3.1	3.0	3.6	4.4	5.4
S3	2.4	3.9	3.5	3.4	4.5	4.8
MEAN	1.76	3.36	3.1	3.3	4.26	4.9

The graph of the simulation results is given in Figure 4.47.

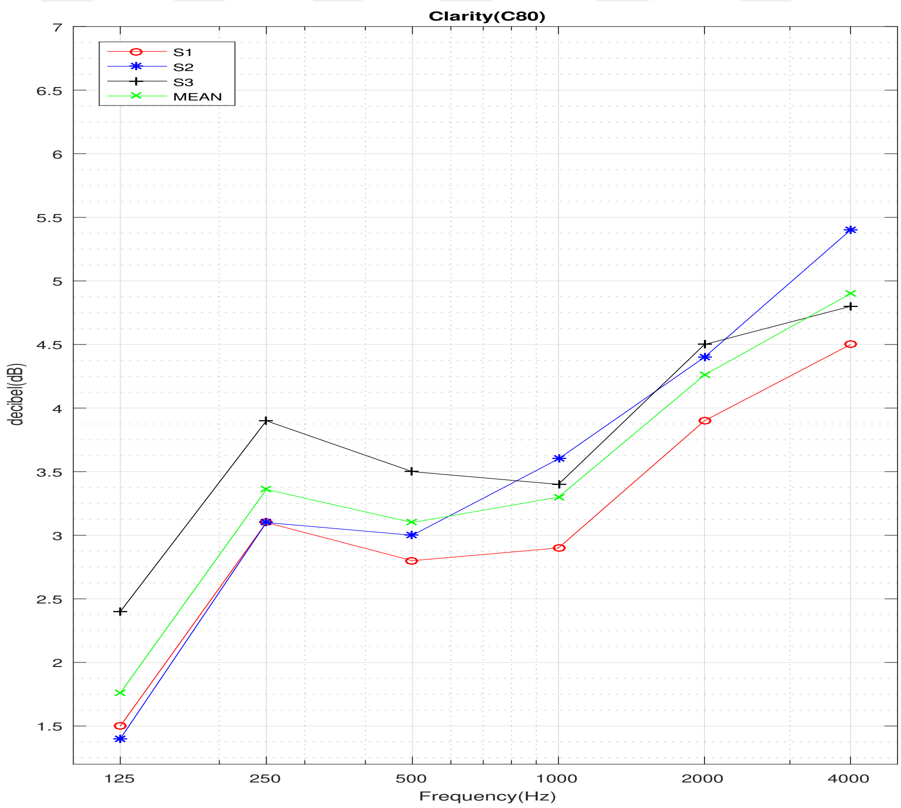

Figure 4.47 Simulated Results of C_{80} Values for the Auditorium.

The C_{80} is 3.2 dB at mid frequencies according to the results. While the clarity parameter tends to increase from 125 Hz to 250 Hz, it falls at 500 Hz and then begins to rise again as the frequency increases. The C_{80} values obtained at the third source point at 125, 250 and 500 Hz are higher than the values measured at the other source points. At 1000 and 4000 Hz, higher values were obtained at the second source point than other points.

Distribution of Speech Transmission Index (STI) in the hall

The STI values simulated for the Auditorium are given according to the source positions in Table 4.33.

Table 4.33 Simulated Results of STI Values for the Auditorium.

Source	STI	STI-Female	STI-Male
S1	0.43	0.40	0.35
S2	0.39	0.37	0.32
S3	0.45	0.42	0.37
MEAN	0.42	0.39	0.34

According to the results obtained by the simulation, the STI value is 0.42. The STI-Female value is 0.39, while the STI-Male value is 0.34.

4.3.3 Comparison of Measurement and Simulation Results with Standard Values

In this section of the thesis, the measurement and simulation results of the Cultural Centers in Gaziantep University are compared. The obtained results were evaluated for low, medium and high frequency distribution averages as specified in the ISO 3382 Standard. In this system, the low frequency mean values are calculated for 125 and 250 Hz, medium frequency mean values 500 and 1000 Hz, high frequency mean values 2000 and 4000 Hz.

Results for the Atatürk Cultural Center

Since ACC is mostly used for theater and conference purposes, it will be evaluated by using $Background\ Noise\ Level, EDT, RT, T_s, D_{50}$ and STI parameters which are used to determine the acoustic qualities of Speech Halls.

All of the noises that affect the interior and exterior of the space are defined as background noises. Background noise is caused by noise from outside traffic, ventilation noise from inside the room, and noise caused by the used electronic devices.

The value of the background noise levels for ACC will be examined by taking into account the acceptable noise level concept described in Chapter 3.2.1 "The Background Noise and NC Curves".

The results obtained by averages of the eight receiver points of the hall, background levels, are given in Table 4.34. The NC-20 is considered as the limit value for conferences and theater halls.

Table 4.34 The Background Noise Level Results of ACC.

Background Noise Level [dB]	Frequency [Hz]					
	125	250	500	1000	2000	4000
Measured	30.4	33.8	38.3	37.5	32.9	24.9
NC-20	40	33	26	22	19	17

According to the measurement results, the existing background noise in the room exceeds the acceptable level in medium and high frequencies.

The EDT parameter associated with the first part of the sound decay curve in volume is directly related to the shape of the room. The EDT values obtained at ACC are given in Table 4.35.

Table 4.35 The EDT Results of ACC.

EDT [s]	Frequency [Hz]		
	125-250	500-1000	2000-4000
Field Measurement	1.11	0.95	0.84
Simulation	1.28	1.00	0.88

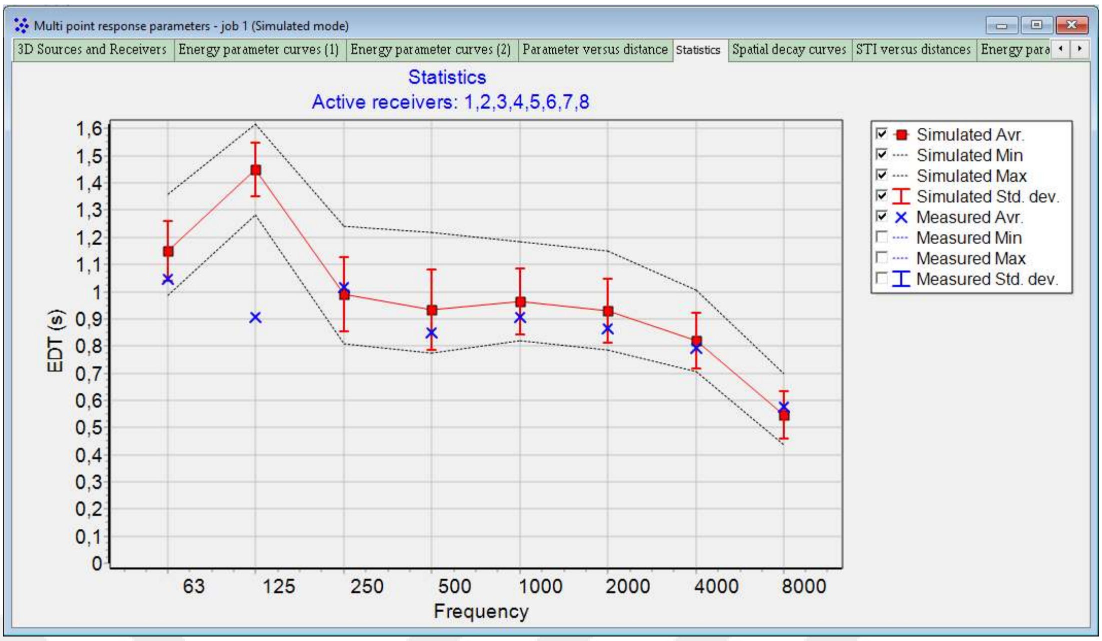

Figure 4.48 Statistics of EDT for ACC in ODEON.

Simulation values are slightly high the measurement values and this difference is more noticeable at low frequencies. A more consistent result is obtained between the results of measurement and simulation methods at medium and high frequencies.

It is expected that ACC will have almost the same values as the RT parameter for the EDT parameter because it is used for speech purposes today. The measured RT parameter is 0.98 s at medium frequencies, likewise, the EDT parameter is 0.95 s. Since the hall has a sufficiently diffuse sound field, the EDT parameter can be calculated based on the RT.

The Reverberation Time is one of the most important parameter used to determine the acoustic qualities of a volume. The RT values obtained at the ACC are given in Table 4.36.

Table 4.36 The RT Results of ACC.

RT [s]	Frequency [Hz]		
	125-250	500-1000	2000-4000
Field Measurement	1.21	0.98	0.83
Simulation	1.17	0.90	0.82

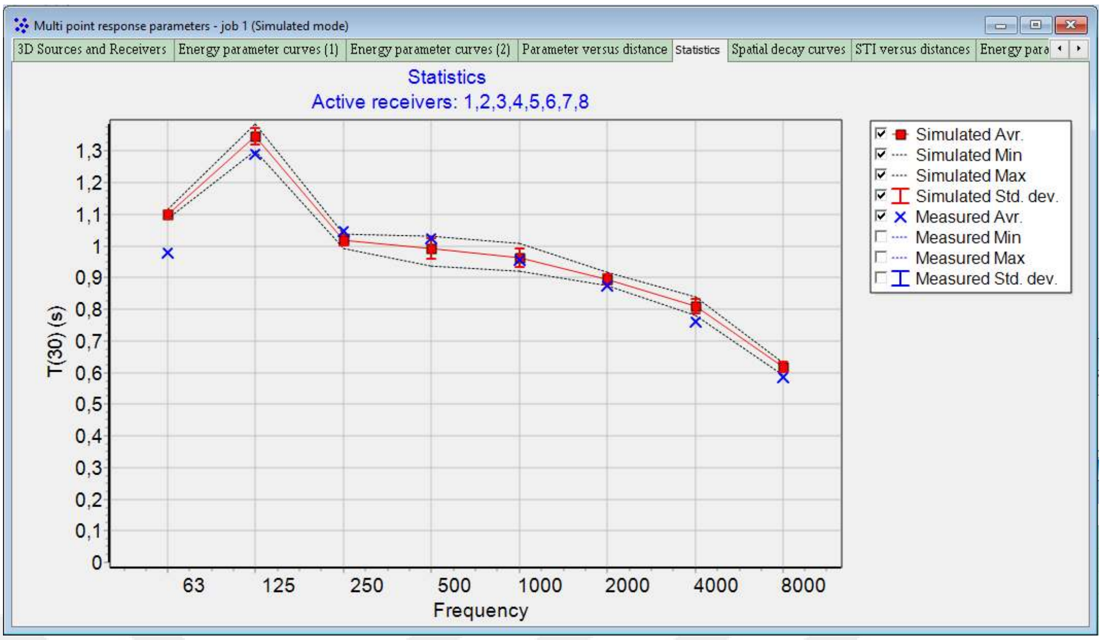

Figure 4.49 Statistics of RT for ACC in ODEON.

The RT parameter is nominated as T_{20} and T_{30} in ODEON. In this thesis, the reverberation time is symbolized as RT to obey the common correspond symbol used in literature. Obtained field measurement and simulation results are consistent with each other. The RT is decreasing, since the absorption of air is greater at higher frequencies. It is seen that the RT at the hall is smaller than the 1.7 s - 2.3 s recommended in the ODEON analysis program.

Another parameter obtained in the calculations for the halls is Centre Time (T_s) parameter, the simulation results and the field measurement results are in good agreement with each other.

Table 4.37 The T_s Results of ACC.

T_s [ms]	Frequency [Hz]		
	125-250	500-1000	2000-4000
Field Measurement	85.80	54.25	56.26
Simulation	81.75	56.75	51.75

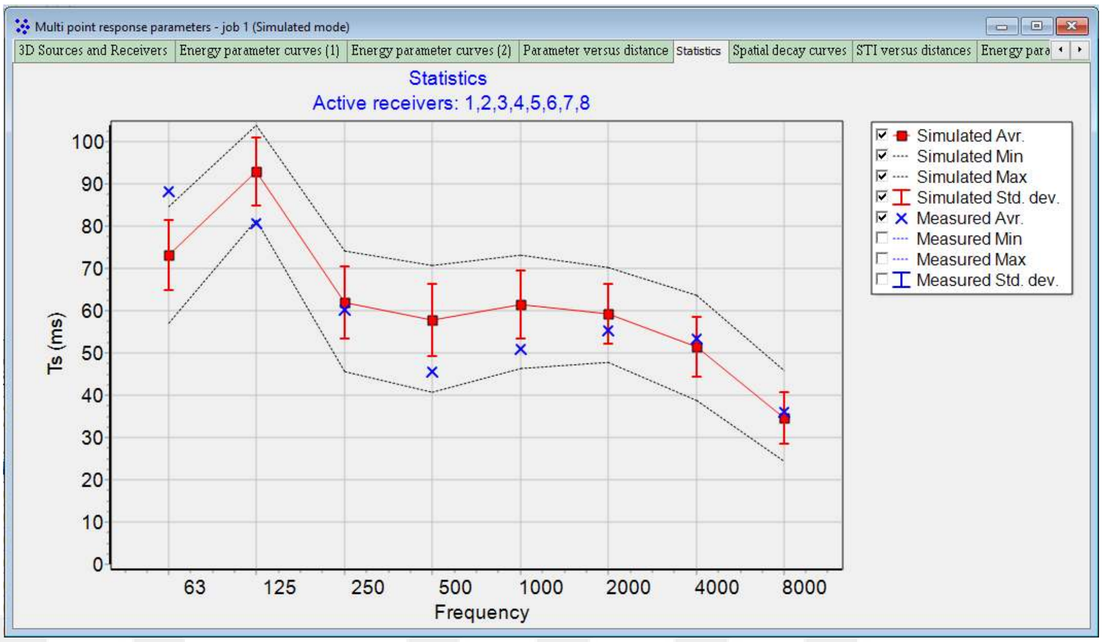

Figure 4.50 Statistics of T_s for ACC in ODEON.

From Table 4.37, it can be seen that at medium and high frequencies of the T_s value is not within the recommended range of 60 ms to 260 ms in ISO 3382-1. The low value of this parameter indicates that the majority of the energy reaches the listener early, thus increasing the value of the clarity (C_{80}) of the sound.

Providing intelligibility is the most important requirement for Speech Halls. The Distinctness (D_{50}) is the rate of early energy coming within 50 ms to total energy. Table 4.38 shows the D_{50} values obtained from the analyzes made for ACC.

Table 4.38 The D_{50} Results of ACC.

D_{50} [-]	Frequency [Hz]		
	125-250	500-1000	2000-4000
Field Measurement	0.47	0.61	0.58
Simulation	0.50	0.62	0.64

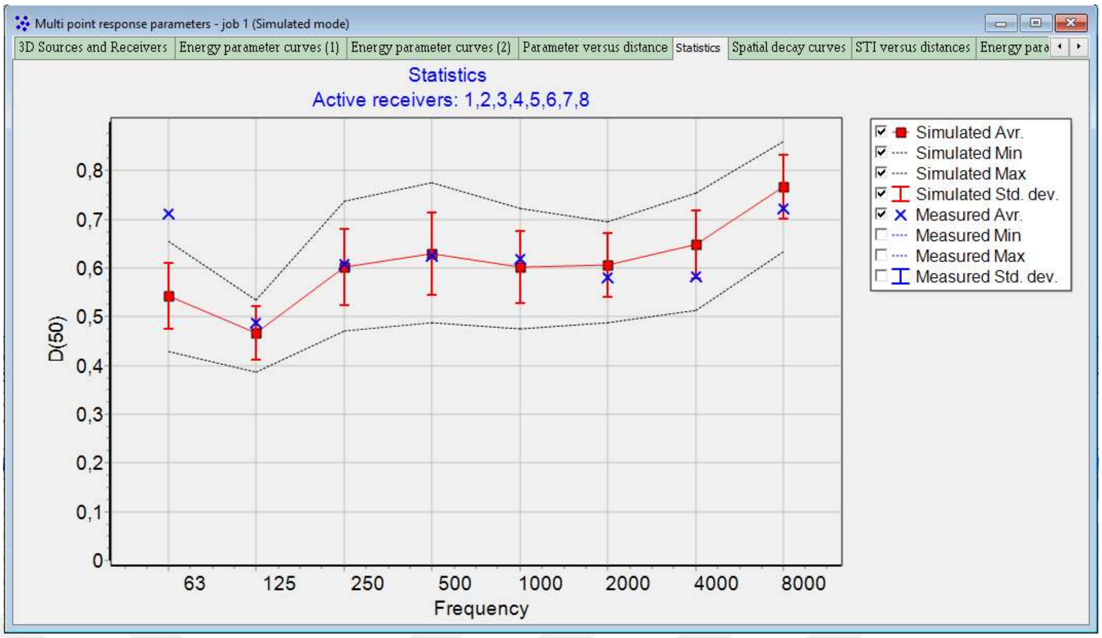

Figure 4.51 Statistics of D_{50} for ACC in ODEON.

The simulation results and the field measurement results are in good agreement with each other. The D_{50} values above 50% provide 90% speech intelligibility. The higher this rate, the better the volume is in terms of intelligibility. The D_{50} value for medium and high frequencies obtained for this hall provides an intelligibility of over 90%.

The STI parameter, which is an important parameter for speech halls, is closely related to background noise and reverberation time. Table 4.39 shows the STI values obtained from the analyzes made for ACC.

Table 4.39 The STI Results of ACC.

	STI	STI-Female	STI-Male
Field Measurement	0.63	0.64	0.59
Simulation	0.56	0.57	0.64

ODEON marks the STI parameter of hall as acoustically *"Good"* since the value of ACC was obtained as 0.63.

Results for the Auditorium

Since the auditorium is used as a multipurpose hall, it will be evaluated using the parameters of $Background\ Noise\ Level, EDT, RT, D_{50}, C_{80}, T_s, BR, TR$ and STI which are used for evaluating the acoustic qualities of both music and speech halls.

The NC-20 Curve is accepted for conferences and theater halls, while the NC-15 is considered as the limit value for concert and opera halls. The results obtained by averages of the sixteen receiver points of the hall, background levels with related NC-Curve values, are given in Table 4.40.

Table 4.40 The Background Noise Level Results of Auditorium.

Background Noise Level [dB]	Frequency [Hz]					
	125	250	500	1000	2000	4000
Measured	27.04	31.98	38.26	36.16	36.11	31.00
NC-15	36	29	22	17	14	12
NC-20	40	33	26	22	19	17

The existing level of background noise measured in the Auditorium exceeds the limit values of the NC15 used in concert and opera halls except for low frequencies. These values are over the entire frequency range of the NC-20 limit values used in conferences and theaters.

The EDT values obtained from the analyzes made in Auditorium are given in Table 4.41.

Table 4.41 The EDT Results of Auditorium.

EDT [s]	Frequency [Hz]		
	125-250	500-1000	2000-4000
Field Measurement	1.45	1.35	1.18
Simulation	1.67	1.48	1.22

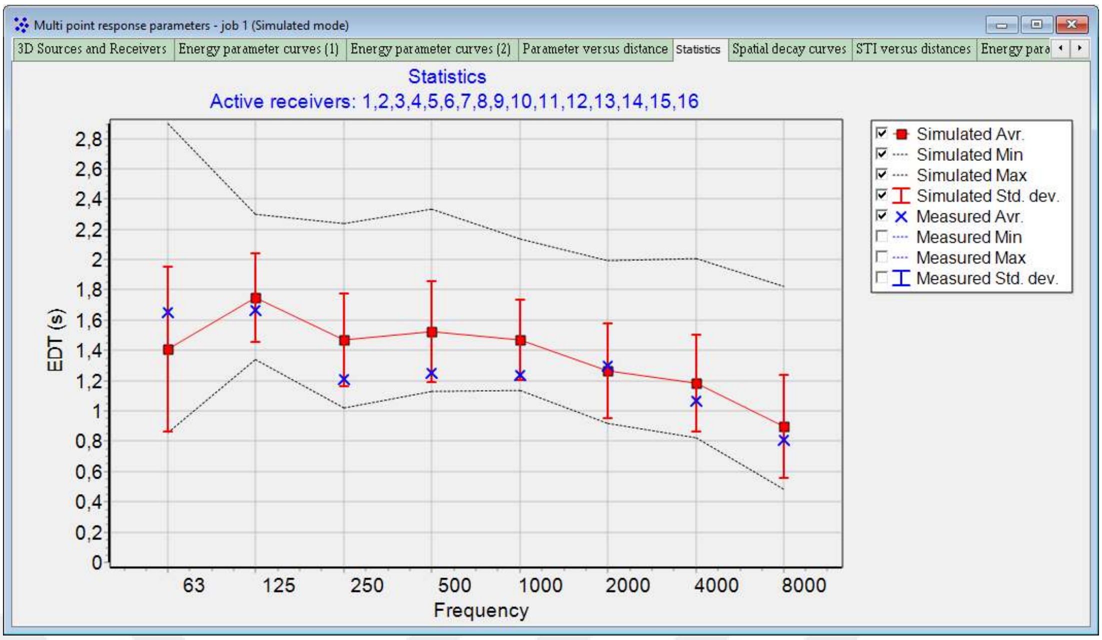

Figure 4.52 Statistics of EDT for the Auditorium in ODEON.

Based on the analysis results, it has been observed that EDT values at many receiver points are within the recommended range of 1.0 s - 3.0 s in ISO 3382-1. The EDT is inversely proportional to the Clarity (C_{80}) parameter. The results will not affect the C_{80} parameter negatively because the results are within the recommended range in the standard. The EDT is influenced by the geometry of the hall, and according to the results of the analysis. This hall seems suitable for both music and speech purpose.

In places where both speaking and musical activities are performed, the ideal reverberation time must be ensured, because the high reverberation time affects the intelligibility of speaking, while the low reverberation time can also cause the sound to disappear.

Table 4.42 The RT Results of Auditorium.

RT [s]	Frequency [Hz]		
	125-250	500-1000	2000-4000
Field Measurement	1.78	1.38	1.01
Simulation	1.70	1.41	1.16

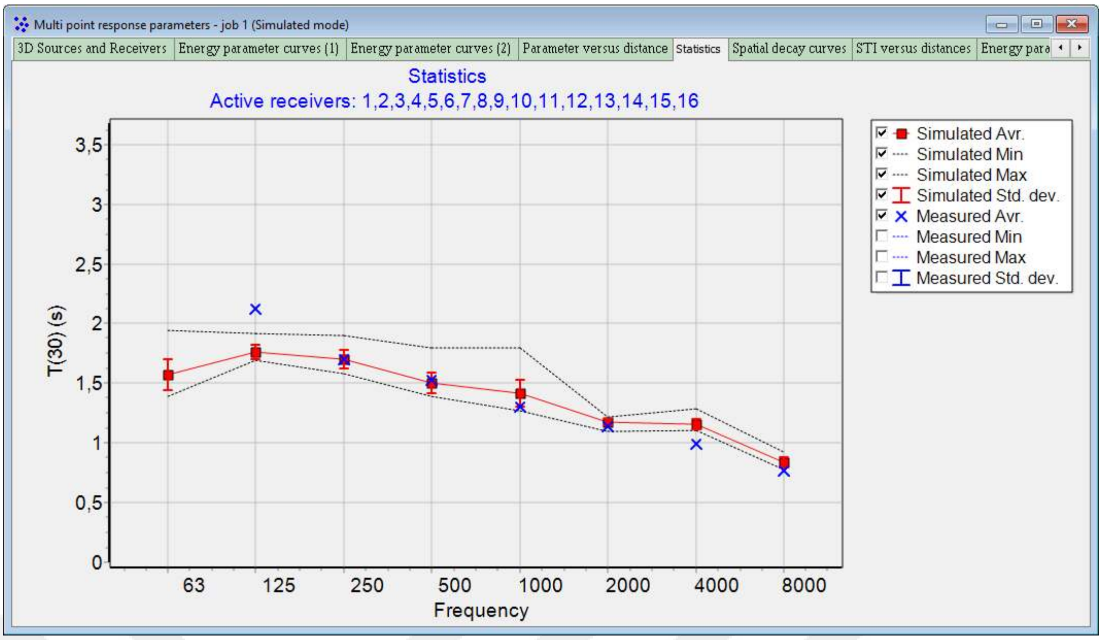

Figure 4.53 Statistics of RT for the Auditorium in ODEON.

The simulation results and the field measurement results are in good agreement with each other. The RT is between the limit values specified by ODEON at low frequencies, but below this value at medium and high frequencies.

When the results of the T_s parameter obtained for the auditorium are examined, the simulation values are lower than the field measurement values, moreover, this difference is observed at higher frequencies.

Table 4.43 The T_s Results of Auditorium.

T_s [ms]	Frequency [Hz]		
	125-250	500-1000	2000-4000
Field Measurement	92.20	80.15	78.88
Simulation	84.50	73.33	57.16

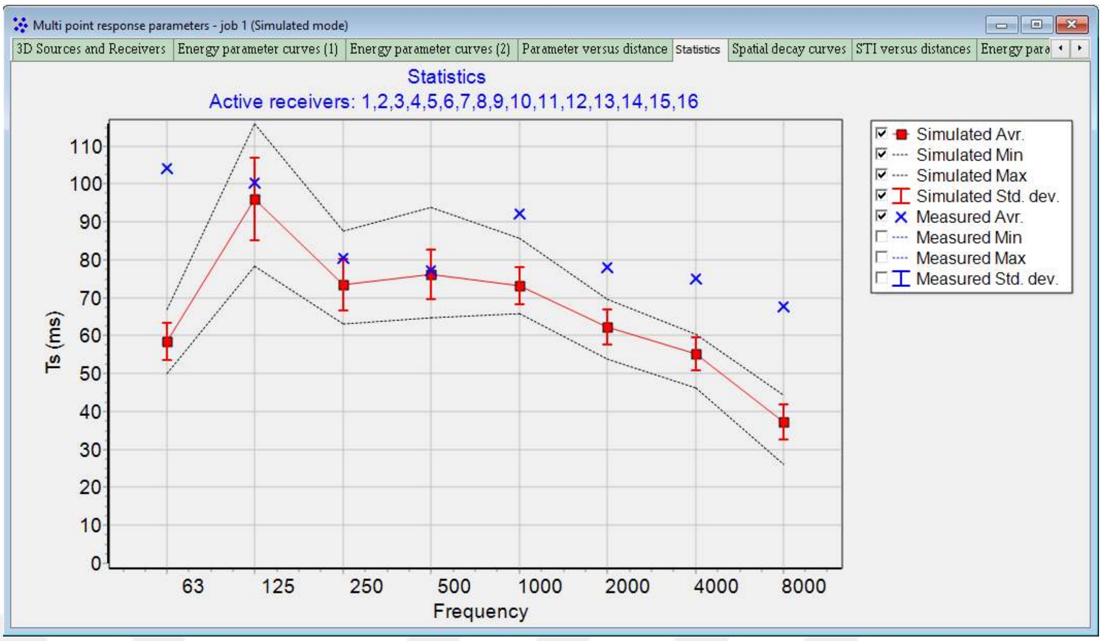

Figure 4.54 Statistics of T_s for the Auditorium in ODEON.

According to the analysis results, it is seen that the Centre Time is in the range of 60 ms - 260 ms that is recommended in ISO 3382-1.

The Distinctness (D_{50}) parameter is used when evaluating speech halls. The measured and modeled D_{50} values in the auditorium are given in Table 4.44.

Table 4.44 The D_{50} Results of Auditorium.

D_{50} [-]	Frequency [Hz]		
	125-250	500-1000	2000-4000
Field Measurement	0.48	0.44	0.42
Simulation	0.54	0.57	0.63

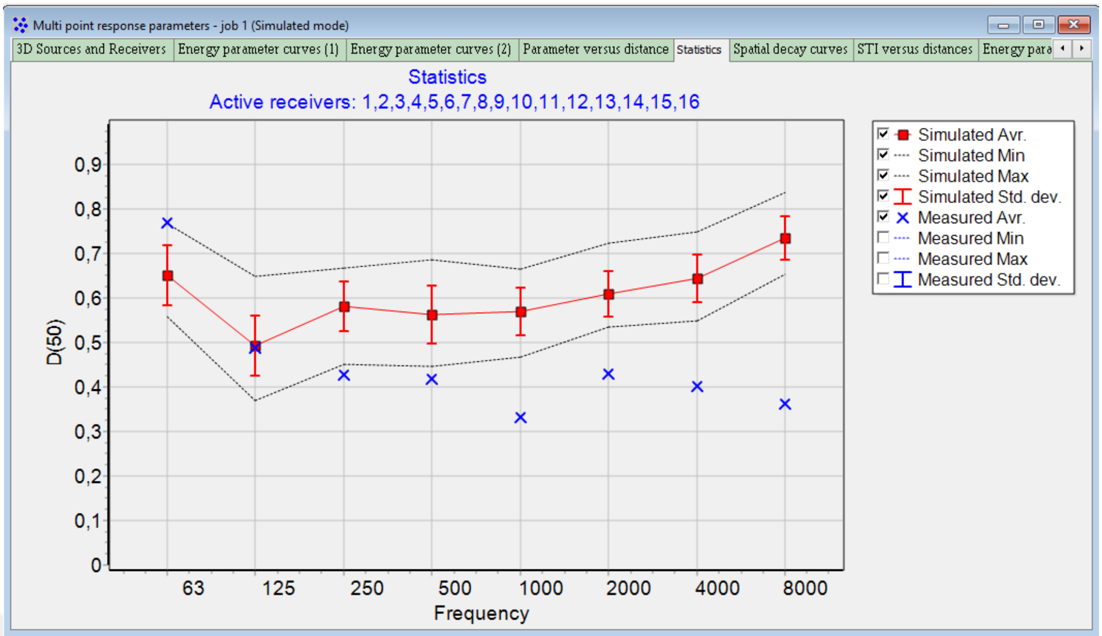

Figure 4.55 Statistics of D_{50} for the Auditorium in ODEON.

The values obtained by simulation are higher than the results obtained with field measurement. The results can be improved, especially at high frequencies, although not so bad. The Distinctness (D_{50}) parameter is inversely proportional to the Early Decay Time (EDT) parameter, and the D_{50} values increase as the EDT decrease.

The C_{80} parameter expresses the balance between clarity and reverberation. There is an inverse proportional relation between the C_{80} parameter and RT. As the RT time lengthens, the early sound energy decreases and the reverberant sound energy increases. In this case, the music will lose its clarity and be expressed with negative values. On the contrary, as the RT decreases, the early sound energy increases. In this case the music will be perceived quite clearly. The table below shows the C_{80} values obtained by simulation and field measurement methods.

Table 4.45 The C_{80} Results of Auditorium.

C_{80} [dB]	Frequency [Hz]		
	125-250	500-1000	2000-4000
Field Measurement	2.35	1.93	2.15
Simulation	2.56	3.20	4.58

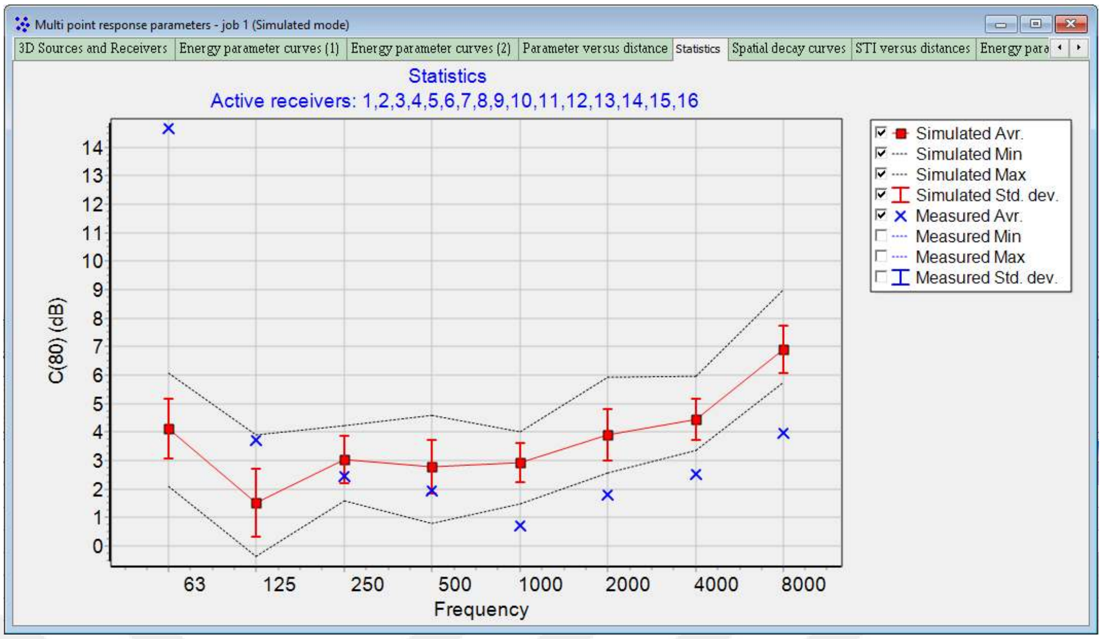

Figure 4.56 Statistics of C_{80} for the Auditorium in ODEON.

As can be seen from Table 4.45, there is a significant difference between simulation and field measurement results. However, the values obtained by the two methods are within the range recommended by ISO 3382-1 standard.

Table 4.46 shows the STI values obtained for the Auditorium.

Table 4.46 The STI Results of Auditorium.

	STI	STI-Female	STI-Male
Field Measurement	0.54	0.52	0.48
Simulation	0.42	0.39	0.34

ODEON marks the STI parameter of hall as acoustically *"Fair"* since the value of the Auditorium was obtained as 0.63.

CHAPTER 5

CONCLUSION

Within the scope of this thesis, the appropriateness of Cultural Centers of Gaziantep University for speech and music activities was examined and evaluated in terms of room acoustics. During the evaluation, three dimensional models of cultural centers were sketched and analyzed in ODEON13 Combined simulation program. Subsequently, measurements were performed on the field and the obtained corresponding data was compared and evaluated in the light of literature information and standards.

A building is expected to provide natural acoustic comfort conditions with the architectural features of the building without electro-acoustical retrofitting systems. Therefore, electro-acoustical systems were excluded from the aim of this study.

If the results obtained by two method, measurements performed by simulation program and in the field, are examined, the following evaluation can be made for the room acoustical parameters.

Background Noise Level;

The sound pressure levels obtained at the Cultural Centers of the Gaziantep University are shown that the Background Noise Levels were above the limits specified by the Ministry of Environment and Forestry. It can be thought that the corresponding parameter was high due to the ventilation systems of noise sources in the halls. The existing background noise level can be reduced to acceptable values thanks to taking precaution for these noise sources such as vibration isolation or isolation on the noise sorce.

Early Decay Time (EDT);

Bistafa and Granado stated that EDT should be smaller than 1.00 s in halls of speech purposes. As a result of the analyzes made in ACC, the EDT parameter was obtained as 0.95 s. EDT and RT values were almost equal except for corresponding values at low frequencies.

The EDT parameter ensures optimum values and confirms the relationship of EDT < RT at low and medium frequencies. At high frequencies, the RT value was 0.83 s while the EDT value was 0.84 s.

Although the EDT values (1.18 s - 1.45 s) obtained in the evaluation of auditorium as a hall for music purposes were in conformity with the ISO3382-1 standard,it were not obey the standard values recommended by Baranek, Barron and ODEON. For speech purposes it shows that the room is suitable for speech activities because it provides the criterion of being close to the RT value of the expected EDT value in a diffuse field even though it is outside the optimum values.

Since the EDT and RT values are very close to each other at medium frequencies, we can talk about the proper sound diffusion of the auditorium. As in ACC, it is observed here that the EDT value at higher frequencies is higher than the RT value. The EDT values obtained on both cultural centers represent the clarity of the sound in the halls.

The EDT value can be evaluated together with the subjective Brilliance parameter. While the Brilliance value of 0.94 s was obtained for 2000 Hz, for 4000 Hz it was obtained 0.8 s which meets the optimum values given in the standard. Therefore, it can be concluded that the auditorium has brilliance sound.

Reverberation Time (RT);

Reverberation time value plays an important role in acoustic design. We can have pre-information about acoustic quality of halls without checking other room acoustics parameters by knowing only RT values. In the literature, there are a different optimum values for RT for same facilities.

The RT values of 0.98 s obtained at medium frequencies in ACC provide the optimum values specified by Barron, Maekawa and Bistafo - Granado for speech purposes halls. These values do not meet the optimum values of any activity except the speech. It confirms the idea of using ACC only for speech purposes after the opening of the Auditorium, which had previously been used for multiple purposes.

In the literature, it is seen that when the optimum values of the halls used as multipurpose rooms are examined, the RT value is 1.3 s - 1.5 s [1]. When the halls are handled separately for their intended use, the RT value has a wide range from 1.0 s to 2.3 s as given in Chapter 3.2.5. The 1.38 s value measured in the medium frequency is outside of the optimal value for music, theater and conference rooms, although it should be within the required range of multipurpose auditoriums. In such cases, the use of electro-acoustic systems excluded from the thesis should be considered for improving room acoustics parameters.

In general, multi-purpose halls need to have movable acoustic panels, reflectors, the solutions for decrease or increase the volume in order to balance the RT value according to the purpose of use. At such conditions, the auditorium is not suitable for every kind of activities.

Bass Ratio (BR) and Treble Ratio (TR);

Other parameters that are used when assessing the acoustic qualities of halls used for music purpose are BR and TR. The results of field measurements at auditorium yielded a value of 1.28 for the BR parameter. The obtained value is at the limit values stated by Baranek. Since this value is greater than one, we can talk about the sound warmth for this hall. A value of 0.73 was obtained for the TR parameter.

Centre Time (T_s);

The values of T_s at medium and high frequencies were measured as 54.25 - 56.26 ms in ACC measurements and can not meet ISO3382-1 optimum values. This value was 85.8 ms at low frequencies and corresponds to the value range specified in the standard. This indicates that the early sound energy is too high for low frequencies, and the lower the value, the greater the clarity of the sound.

The T_s values measured in the auditorium were in the range from 78.88 ms to 92.2 ms. These values meet the optimum values, but also indicate the high value of early sound energy and the clarity of the sound. The T_s value is inversely proportional to the C_{80} value, directly proportional to the RT and EDT values. The corresponding values at medium frequencies are in the optimum range. This multi-relation was used in the evaluation of the auditorium used for music purposes and was not taken into account for speech purposes at ACC.

Distinctness (D_{50});

The average D_{50} value in ACC used for speech in the university was obtained in the range of 0.3 - 0.7 specified in ISO3382-1 standard in all frequency bands and it achieves $D_{50} > 0.5$ which is intelligibility criterion except low frequencies.

In the multipurpose auditorium, the values obtained provide an intelligibility of less than 90%, as suggested by Kuttruff, although it conforms to the ISO standard.

Clarity (C_{80});

The C_{80} value expected at different value ranges according to the purpose of use of the halls is optimum between 0 dB and 4 dB in lecture halls, while it has a value between -4 dB and -1 dB in unoccupied concert halls. The C_{80} value in the auditorium without audience ranges from 1.93 dB to 2.35 dB. The fact that the seat upholstery used in the auditorium has a high sound absorbing feature prevented the specified negative C_{80} values from being measured. It is concluded that these results are whithin the range of the values recommended by Barron and Baranek, and ISO3382-1 standard.

Speech Transmission Index (STI);

The STI parameter, which is an important parameter for speech halls, is closely related to Background Noise Level and Reverberation Time and the closer it is to 1.00, the greater the intelligibility of speech. ODEON marks the STI parameter of hall as acoustically *"Good"* since the value of ACC was obtained as 0.63. On the other hand, the same parameter was obtained at the Auditorium as 0.54 which was marked as *"Fair"*.

From the conclusion of all acoustical parameters, it can be said that ACC is only available for speech purposes usage. To overcome this disadvantage, some acoustical solutions should be treated.

In a similar manner, Auditorium results are shown that it can be used for most facilities without speech purposes usage.

REFERENCES

[1] Cowan J. (2000). Architectural Acoustics Design Guide. Mc Graw Hill.

[2] İlisulu S.G. (2010). Acoustical Analysis of a Theatre: İstanbul Metropolitan Municipality Beyoğlu Theatre as a Case Study. M.Sc. Thesis. Gazi University.

[3] Rossing T. (2007). Springer Handbook of Acoustics. Springer.

[4] Özkartal N.E. (2011). Analyse of Acoustical Comfort Parameters Concert Halls with a Case Study. M.Sc. Thesis. Gazi University.

[5] Kurtulan Z. (2009). M. S. G. S. Ü. Sedad Hakkı Eldem Oditoryumunun Hacim Akustiği Açısından İncelenmesi ve Değerlendirilmesi. M.Sc. Thesis. Yıldız Technical University.

[6] Demirkale S. Y., S. Y. Budak S. Y. (1995). Acoustical Performance of the Grand of the Atatürk Cultural Center. *Applied Acoustm.* **45** . 291-319.

[7] Gramez A., Boubenider F. (2017). Acoustic comfort evaluation for a conference room: A case study. *Applied Acoustics.* **118**. 39-49.

[8] N. G. Kanev, A. Ya. Livshits, and H. Möller. (2013). Acoustics of the Great Hall of the Moscow State Conservatory after Reconstruction in 2010–2011. *Acoustical Physics.* **59(3)**. 361–368.

[9] Watchman M., Potvin A., and C. M. H. Demers. (2017). Wood and Comfort: A comparative case study of two multifunctional rooms. *BioResources.* **12(1)**. 168-182.

[10] Kurtay C., Demet Eryıldız D. I., Harputlugil G. U. (2008). Acoustical Performance Evaluation of Mimar Kemaleddin Hall and Alternatives for Performance Improvement. *J. Fac. Eng. Arch.* **23(3)**. 557-568.

[11] Özgencil Y. (2015). Acoustic Examination and Improving Acoustic Design of Conservatory Rehearsal Rooms. M.Sc. Thesis. Bahcesehir University.

[12] Türk E. (2011). Investigation and Evaluation of Acoustic Quality of Halls in İstanbul. M.Sc. Thesis. Yıldız Technical University.

[13] Gürkan E. (2013). Analysis of the Horseshoe Planned Halls Functioned for Concert and Opera in Terms of Acoustic Design. M.Sc. Thesis. İstanbul Technical University.

[14] Ateş E.G. (2007). Kültür Mirasımız Olan Yerebatan Sarnıcının Akustik Sorunlarının İncelenmesi. M.Sc. Thesis. İstanbul Technical University.

[15] Türkmen R. (2013). The Development of Improved Design Parameters on the Enhancement of Acoustic Parameters on the Enhancement of Acoustic Performance in Auditoriums and a Case Study. Ph.D. Thesis. Gazi University.

[16] Şahin Ö. (2007). Konuşma Amaçlı Hacimlerde Kaynak Konumu Değişiminin Hacim Akustiği Parametreleri Üzerindeki Etkisinin İncelenmesi. M.Sc. Thesis. Yıldız Technical University.

[17] Karaman Ö.Y. (2009). A Modelling Method for Optimising the Seating Arrangement at the Acoustical Design Stage of Halls. Ph.D. Thesis. Dokuz Eylül University.

[18] Atça E. (2013). Acoustic Design Based on Multi-Aspect Performance Analysis. M.Sc. Thesis. İzmir Institute of Technology.

[19] Örün G. (2011). Acoustical Analysis and Taxonomy of Performance Halls in Early Republican Period in Ankara: Resim Heykel Müzesi, Küçük Tiyatro and Opera. M.Sc. Thesis. Middle East Technical University.

[20] Sü Z. (2004). Acoustical Performance Analysis of Bilkent University Amphitheater "ODEON". M.Sc. Thesis. Bilkent University.

[21] Çalışkan E.B. (2010). Acoustical Evaluation of Shopping Mall Typology. M.Sc. Thesis. Middle East Technical University.

[22] Sü Z. (2010). Assessment of Non-Exponential Sound Energy Decays Within Multi-Domed Monuments by Numerical and Experimental Methods. Ph.D. Thesis. Middle East Technical University.

[23] David A. Bies, Colin H. Hansen. (2003). Engineering Noise Control Theory and Practice. Spon Press.

[24] Sirel O. (2000). Ses Yalıtımı Konusunda Birkaç Açıklama. *Yalıtım Dergisi*. **26**.

[25] Maekawa Z., Rindel J.H., Lord P. (2011). Environmental and Architectural Acoustics. Spon Press.

[26] Randall F. Barron. (2003). Industrial Noise Control and Acoustics. Marcel Dekker Inc.

[27] Kuttruff H. (2009). Room Acoustics: Fifth Edition. Spon Press.

[28] K.B. Ginn. (1978). Architectural Acoustics. B&K.

[29] Anthony O. E., Jones A. O., Oyedele O. A. (2007). A Technical report on the behavior of sound in an enclosed space.

[30] Barron M. (2010). Auditorium Acoustics and Architectural Design. Second Edition. Spon Press.

[31] Beranek L. (1962). Music, Acoustics and Architecture. John Wiley&Sons Inc.

[32] Bayazıt N. T. (1999). Geometric Design Method for the Acoustic Evaluation of Rectangular Cross-sectioned Concert Halls. Ph.D. Thesis. İstanbul Technical University.

[33] Maxfield, J.P., Albersheim, W.F. (1947). An Acoustic Constant of Enclosed Spaces Correlatable with their Apparent Liveness. *Journal of the Acoustical Society of America.* **19(1)**. 71-79.

[34] Beranek L. (2004). Concert Halls and Opera Houses: Music, Acoustics and Architecture. Springer.

[35] Mehta M., Johnson J., Rocafort J. (1999). Architectural Acoustics: Principles and Design. Prentice Hall.

[36] Beranek L. (1996). Concert and Opera Halls: How They Sound. Acoustical Society of America.

[37] Çevre ve Orman Bakanlığı. (2010). Çevresel Gürültünün Değerlendirilmesi ve Yönetimi Yönetmeliği. Çevre ve Orman Bakanlığı Raporu 27601. Resmi Gazete.

[38] `http://personal.cityu.edu.hk/~bsapplec/single.htm`. 11.12.2017

[39] Egan M. D. (2007). Architectural Acoustics. Mc Graw Hill.

[40] ISO 3382-1 (2009) Acoustics – Measurement of Room Acoustic Parameters, Part 1: Performance Spaces.

[41] Christensen C. L., Koutsouris G. (2015). ODEON Room Acoustics Software Version 13 User's Manual. ODEON.

[42] Figueiredo F. L., Iazzetta F. (2005). Comperative Study of measured acoustic parameters in concert halls in the city of Sao Paulo. Inter – Noise Rio 2005.

[43] Cavanaugh J. W., Wilkes A. J. (1999). Architectural Acoustics Priciples and Practice. John Wiley & Sons Inc.

[44] Long M. (2014). Architectural Acoustics. Elsevier Academic Press.

[45] Templeton D. (1997). Acoustics in The Built Environment: Advice for The Design Team. Architectural Press.

[46] Beranek L. (1993). Concert Halls and Opera Houses. Cambridge.

[47] Beranek L. (1992). Concert Hall Acoustics-1992. *Journal of Sound and Vibration.* **92(1)**. 1-39.

[48] Product Data, DIRAC Room Acoustic Software Type-7841, Brüel&Kjaer.

[49] Product Data, Sound Sources and Impact Sound Source for Building Acoustics, Brüel&Kjaer.

[50] `https://www.bksv.com/en/products/transducers/acoustic/calibrators/4231`. 11.12.2017

[51] `http://www.m-audio.com/products/view/m-track-mkii`. 11.12.2017

[52] Bistafa S.R., Granado M.V. (2002). Objective Measurements of Speech Intelligibility in Proscenium Type of Theatres. *XX Encontro da Sociadade Brasileira de Acustica-SOBRAC*. 1-6

[53] Bistafa S.R., Granado M.V. (2005). A Survey of The Acoustic Quality For Speech in Auditoriums. *Electronic Journal Technical Acoustics*. **15**. 1-16

APPENDIX A

ACC MEASUREMENT RESULTS

Table A.1 Measured Background Noise Level Results at ACC.

The Background Noise Level [dB]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000	LAeq
R1	30.4	33.1	37.3	36.4	32.5	24.8	41.8
R2	30.1	33.9	37.6	36.7	31.9	23.9	42.0
R3	30.9	34.0	38.8	37.6	33.2	25.7	42.9
R4	30.6	34.1	38.9	38.1	33.9	24.8	43.2
R5	31.0	34.4	39.0	38.2	33.4	25.3	43.3
R6	30.6	33.6	38.1	37.7	33.2	24.5	42.6
R7	30.0	34.0	38.5	37.7	32.9	24.8	42.8
R8	30.1	33.7	38.5	38.0	32.9	25.5	42.8

Table A.2 Measured EDT Results at ACC Using by Interrupted Method.

Interrupted Method - EDT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.18	0.52	0.89	0.92	0.92	0.78
R2	2.35	1.14	1.16	1.14	0.98	0.88
R3	2.07	0.93	0.91	0.95	1.07	0.76
R4	1.79	0.79	1.05	0.90	0.97	0.84
R5	1.17	0.95	1.19	0.83	1.05	1.11
R6	2.39	1.35	1.08	1.05	1.03	0.74
R7	1.45	1.25	1.03	1.01	0.94	0.87
R8	1.95	0.82	0.98	1.12	0.83	0.77

Table A.3 Measured RT Results at ACC Using by Interrupted Method.

Interrupted Method - RT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.07	0.94	0.96	0.97	0.93	0.80
R2	1.22	0.94	1.04	0.96	0.95	0.82
R3	1.17	0.99	0.99	0.96	0.92	0.95
R4	1.67	1.04	1.06	1.02	0.97	0.85
R5	1.48	1.04	0.97	1.01	0.98	0.90
R6	1.43	0.97	1.03	1.09	0.98	0.89
R7	1.05	1.18	0.98	1.00	1.04	0.92
R8	1.75	1.11	0.95	1.08	1.00	0.93

Table A.4 Measured EDT Results at ACC (at S1).

EDT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	0.92	1.02	0.82	0.90	0.90	0.78
R2	0.93	1.06	0.80	0.89	0.92	0.77
R3	0.91	1.00	0.88	0.92	0.85	0.81
R4	0.93	1.00	0.89	0.88	0.83	0.81
R5	0.91	1.01	0.85	0.91	0.86	0.78
R6	0.91	1.00	0.88	0.92	0.84	0.81
R7	0.89	0.99	0.81	0.91	0.86	0.78
R8	0.90	1.00	0.85	0.91	0.85	0.80

Table A.5 Measured RT Results at ACC (at S1).

RT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.31	1.06	1.02	0.96	0.87	0.76
R2	1.25	1.04	1.03	0.96	0.88	0.74
R3	1.30	1.06	1.02	0.95	0.88	0.76
R4	1.27	1.05	1.01	0.95	0.87	0.76
R5	1.29	1.07	1.04	0.95	0.87	0.77
R6	1.28	1.06	1.02	0.95	0.86	0.76
R7	1.30	1.06	1.03	0.96	0.88	0.77
R8	1.28	1.05	1.03	0.95	0.88	0.77

Table A.6 Measured T_s Results at ACC (at S1).

T_s [ms]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	83.00	61.33	47.33	52.33	60.33	54.33
R2	83.33	59.00	45.33	50.33	59.33	52.66
R3	81.00	60.00	45.00	51.00	53.66	52.33
R4	82.66	62.00	47.33	52.00	56.00	54.66
R5	81.33	60.66	45.33	50.66	54.33	52.00
R6	80.66	61.66	47.00	54.33	56.66	56.00
R7	81.00	62.66	47.33	53.33	56.00	57.33
R8	79.66	61.00	46.33	53.66	54.33	54.66

Table A.7 Measured D_{50} Results at ACC (at S1).

D_{50} [-]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	0.37	0.57	0.64	0.61	0.54	0.58
R2	0.46	0.61	0.63	0.61	0.53	0.58
R3	0.46	0.61	0.64	0.63	0.60	0.59
R4	0.45	0.59	0.63	0.61	0.57	0.57
R5	0.47	0.60	0.62	0.62	0.59	0.60
R6	0.50	0.59	0.60	0.59	0.58	0.57
R7	0.47	0.57	0.59	0.58	0.57	0.55
R8	0.48	0.59	0.62	0.6	0.60	0.59

Table A.8 Measured C_{80} Results at ACC (at S1).

C_{80} [dB]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	3.56	5.20	5.80	4.80	3.53	4.60
R2	3.43	5.30	5.86	4.90	3.66	4.76
R3	3.76	5.23	5.76	4.96	4.70	4.70
R4	3.56	5.20	5.56	5.00	4.56	4.46
R5	3.66	5.36	5.83	5.06	4.50	4.96
R6	3.90	5.06	5.43	4.76	4.40	4.36
R7	4.16	5.33	5.63	4.63	4.40	4.50
R8	3.96	5.13	5.63	4.83	4.56	4.56

Table A.9 Measured STI Results at ACC (at S1).

Receiver	STI	STI-Female	STI-Male
R1	0.64	0.64	0.59
R2	0.64	0.64	0.59
R3	0.64	0.65	0.60
R4	0.64	0.65	0.60
R5	0.64	0.65	0.60
R6	0.64	0.65	0.60
R7	0.64	0.65	0.60
R8	0.64	0.65	0.60

Table A.10 Measured EDT Results at ACC (at S2).

EDT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.65	0.88	1.02	1.07	0.90	0.84
R2	1.66	0.90	0.98	1.09	0.96	0.87
R3	1.60	0.90	1.01	1.06	0.88	0.84
R4	1.60	0.89	1.03	1.05	0.87	0.82
R5	1.60	0.89	0.98	1.07	0.94	0.86
R6	1.65	0.87	0.98	1.06	0.87	0.84
R7	1.63	0.89	1.01	1.10	0.96	0.87
R8	1.67	0.87	1.01	1.09	0.86	0.84

Table A.11 Measured RT Results at ACC (at S2).

RT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.52	1.10	1.04	0.96	0.94	0.81
R2	1.49	1.10	1.02	0.96	0.93	0.80
R3	1.36	1.08	1.03	0.95	0.93	0.80
R4	1.38	1.09	1.03	0.96	0.94	0.80
R5	1.36	1.09	1.02	0.96	0.94	0.78
R6	1.41	1.09	1.04	0.97	0.94	0.79
R7	1.43	1.10	1.03	0.96	0.92	0.79
R8	1.50	1.10	1.03	0.97	0.95	0.81

Table A.12 Measured T_s Results at ACC (at S2).

T_s [ms]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	130.33	70.00	58.00	62.00	62.66	52.66
R2	132.66	71.66	57.66	63.33	66.00	55.33
R3	128.66	71.00	56.66	61.66	62.00	51.00
R4	129.00	72.00	58.33	60.33	63.66	50.00
R5	126.33	70.00	56.66	61.33	64.00	51.33
R6	135.00	71.00	56.00	60.33	61.33	51.33
R7	128.66	70.00	57.33	65.33	65.66	53.00
R8	132.00	66.66	55.00	57.66	57.33	48.66

Table A.13 Measured D_{50} Results at ACC (at S2).

D_{50} [-]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	0.32	0.51	0.65	0.59	0.56	0.63
R2	0.35	0.51	0.65	0.59	0.53	0.61
R3	0.37	0.49	0.64	0.58	0.56	0.64
R4	0.37	0.48	0.63	0.58	0.54	0.64
R5	0.41	0.51	0.66	0.59	0.55	0.64
R6	0.38	0.49	0.67	0.61	0.57	0.63
R7	0.41	0.51	0.65	0.56	0.54	0.63
R8	0.38	0.53	0.67	0.61	0.60	0.64

Table A.14 Measured C_{80} Results at ACC (at S2).

C_{80} [dB]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.90	4.30	5.06	3.86	4.13	5.10
R2	1.53	4.26	5.46	3.80	3.63	4.53
R3	1.96	4.43	5.20	3.93	4.33	5.40
R4	2.00	4.30	5.13	3.96	4.03	5.46
R5	2.33	4.56	5.36	4.00	4.06	5.23
R6	1.73	4.43	5.80	4.23	4.40	5.20
R7	2.16	4.53	5.36	3.46	3.70	4.90
R8	2.16	4.80	5.36	4.10	4.70	5.30

Table A.15 Measured STI Results at ACC (at S2).

Receiver	STI	STI-Female	STI-Male
R1	0.63	0.64	0.59
R2	0.63	0.64	0.59
R3	0.63	0.65	0.60
R4	0.63	0.64	0.59
R5	0.63	0.64	0.59
R6	0.63	0.65	0.60
R7	0.62	0.64	0.59
R8	0.63	0.65	0.60

APPENDIX B

AUDITORIUM MEASUREMENT RESULTS

Table B.1 Measured Background Noise Level Results at the Auditorium.

The Background Noise Level [dB]	Frequency [Hz]						
Receiver	125	250	500	1000	2000	4000	LAeq
R1	29.5	34.0	40.9	37.6	37.3	32.4	44.6
R2	27.8	32.5	39.0	37.1	36.2	31.8	43.3
R3	26.3	32.1	38.2	36.6	35.5	30.8	42.6
R4	25.6	30.1	36.2	34.8	33.7	29.1	40.8
R5	28.8	34.6	41.2	37.9	37.5	33.0	44.9
R6	27.7	33.6	39.5	37.8	36.6	32.2	43.9
R7	27.8	33.6	39.5	37.0	36.7	31.8	43.7
R8	26.8	32.6	39.4	37.1	36.9	32.1	43.6
R9	28.1	31.6	40.4	39.6	40.5	35.0	45.7
R10	24.7	30.7	38.0	35.5	35.9	31.2	42.3
R11	27.0	31.5	38.1	36.1	36.4	30.3	42.6
R12	26.5	31.5	37.1	35.2	35.1	29.7	41.7
R13	27.6	31.6	36.7	34.5	35.6	29.7	41.6
R14	26.5	30.3	36.3	34.3	35.1	29.0	41.1
R15	26.0	30.5	36.4	34.1	34.8	29.2	41.0
R16	26.0	31.0	35.4	33.5	34.1	28.7	40.4

Table B.2 Measured EDT Results at the Auditorium Using by Interrupted Method.

Interrupted Method - EDT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	2.04	1.13	1.60	1.46	1.16	1.21
R2	2.24	1.06	1.42	1.32	1.19	0.97
R3	1.44	1.00	1.67	1.15	1.16	0.92
R4	1.33	0.86	1.45	1.38	1.21	0.92
R5	1.38	1.10	1.40	1.17	1.08	0.29
R6	2.81	1.51	1.51	1.20	1.35	0.97
R7	1.45	1.17	1.20	1.43	1.23	1.00
R8	1.41	1.74	1.22	1.40	1.21	0.94
R9	1.49	1.61	1.19	0.97	1.28	0.70
R10	1.30	1.14	1.12	0.97	0.56	0.53

Table B.3 Measured RT Results at the Auditorium Using by Interrupted Method.

Interrupted Method - RT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.57	1.37	1.59	1.43	1.18	0.96
R2	1.64	1.48	1.53	1.45	1.22	0.97
R3	1.59	1.63	1.66	1.45	1.19	0.97
R4	1.55	1.41	1.54	1.39	1.23	0.97
R5	1.44	1.50	1.69	1.49	1.19	0.99
R6	1.47	1.57	1.80	1.54	1.23	1.02
R7	1.71	0.53	1.75	1.43	1.21	1.00
R8	1.66	1.67	1.77	1.49	1.19	1.01
R9	1.44	1.44	1.59	1.51	1.51	1.03
R10	1.85	1.59	2.17	1.43	1.16	1.02

Table B.4 Measured EDT Results at the Auditorium (at S1).

EDT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.53	1.21	1.22	1.36	1.37	1.04
R2	1.54	1.20	1.24	1.35	1.32	1.03
R3	1.50	1.18	1.25	1.28	1.36	1.07
R4	1.52	1.16	1.28	1.21	1.30	1.16
R5	1.59	1.16	1.23	1.26	1.34	1.09
R6	1.56	1.18	1.22	1.29	1.36	1.07
R7	1.61	1.19	1.22	1.29	1.29	1.05
R8	1.77	1.16	1.25	1.25	1.26	1.07
R9	1.75	1.28	1.32	1.10	1.21	1.07
R10	1.81	1.28	1.31	1.13	1.22	1.06
R11	1.71	1.22	1.24	1.19	1.32	1.02
R12	1.70	1.22	1.23	1.19	1.30	1.02
R13	1.70	1.20	1.19	1.19	1.34	1.08
R14	1.73	1.25	1.27	1.28	1.29	1.05
R15	1.74	1.25	1.25	1.25	1.29	1.03
R16	1.75	1.25	1.29	1.15	1.29	1.05

Table B.5 Measured RT Results at the Auditorium (at S1).

RT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	2.15	1.75	1.51	1.30	1.14	1.02
R2	1.63	1.74	1.5	1.32	1.16	1.01
R3	2.03	1.70	1.51	1.29	1.13	0.99
R4	1.69	1.63	1.51	1.30	1.13	0.99
R5	1.73	1.64	1.52	1.29	1.14	0.98
R6	1.82	1.63	1.51	1.29	1.15	0.99
R7	1.77	1.62	1.52	1.30	1.15	1.01
R8	1.86	1.65	1.52	1.29	1.13	1.00
R9	1.48	1.60	1.52	1.32	1.16	0.97
R10	1.48	1.64	1.51	1.32	1.16	0.97
R11	3.40	1.77	1.56	1.32	1.12	0.97
R12	2.86	1.79	1.56	1.32	1.11	0.99
R13	3.35	1.77	1.54	1.32	1.11	0.99
R14	1.79	1.75	1.55	1.29	1.13	0.98
R15	1.81	1.76	1.56	1.29	1.14	0.98
R16	3.10	1.79	1.53	1.31	1.13	0.99

Table B.6 Measured T_s Results at the Auditorium (at S1).

T_s [ms]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	94.00	79.66	73.66	92.33	59.33	66.00
R2	93.00	81.66	78.00	97.66	70.66	74.66
R3	92.66	81.66	75.33	94.00	62.66	64.00
R4	88.00	83.33	76.66	95.66	73.66	72.33
R5	91.66	79.00	74.00	92.66	61.66	65.66
R6	91.66	80.00	75.33	92.00	64.00	72.00
R7	92.66	79.00	75.66	93.00	68.66	67.00
R8	99.33	82.00	79.00	98.00	68.33	67.00
R9	104.66	82.66	84.00	93.00	107.33	98.33
R10	107.33	84.33	84.66	89.00	105.66	94.66
R11	109.33	80.33	75.66	94.00	69.66	68.00
R12	106.33	78.66	76.66	96.00	71.33	72.33
R13	109.66	80.00	76.00	93.66	68.00	66.66
R14	106.00	79.66	77.00	87.00	103.00	84.00
R15	106.66	77.33	76.33	86.66	103.66	82.33
R16	105.33	81.33	77.00	82.66	102.00	99.33

Table B.7 Measured D_{50} Results at the Auditorium (at S1).

D_{50} [-]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	0.39	0.42	0.44	0.39	0.55	0.45
R2	0.48	0.39	0.41	0.34	0.47	0.38
R3	0.41	0.40	0.44	0.36	0.53	0.48
R4	0.43	0.40	0.44	0.31	0.42	0.43
R5	0.43	0.43	0.45	0.35	0.52	0.47
R6	0.39	0.43	0.44	0.37	0.52	0.44
R7	0.51	0.39	0.42	0.37	0.49	0.46
R8	0.46	0.45	0.42	0.31	0.45	0.47
R9	0.48	0.48	0.36	0.25	0.25	0.25
R10	0.49	0.46	0.38	0.29	0.27	0.25
R11	0.59	0.43	0.40	0.34	0.48	0.44
R12	0.55	0.42	0.41	0.30	0.45	0.39
R13	0.43	0.44	0.43	0.32	0.49	0.46
R14	0.51	0.43	0.42	0.34	0.24	0.30
R15	0.48	0.45	0.42	0.32	0.24	0.29
R16	0.51	0.45	0.40	0.36	0.32	0.28

Table B.8 Measured C_{80} Results at the Auditorium (at S1).

C_{80} [dB]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	3.16	2.40	2.36	0.80	3.03	3.56
R2	3.86	2.00	2.10	0.56	1.90	2.60
R3	3.23	2.16	2.36	0.76	3.16	3.70
R4	3.73	2.10	2.03	0.73	2.33	2.63
R5	3.33	2.56	2.30	0.93	3.60	3.50
R6	3.26	2.53	2.36	0.96	3.30	2.96
R7	4.33	2.26	2.40	0.96	2.56	3.46
R8	3.46	2.80	2.10	0.40	2.53	3.40
R9	2.63	2.50	1.03	0.16	-0.93	-0.20
R10	2.90	2.20	1.16	0.56	-0.76	-0.06
R11	4.83	2.60	1.86	0.70	2.26	3.53
R12	4.23	2.60	1.70	0.40	2.20	3.03
R13	2.83	2.76	2.00	0.40	2.23	3.36
R14	3.46	2.36	1.86	1.33	-0.13	1.36
R15	3.33	2.83	1.86	1.23	-0.20	1.70
R16	3.56	2.73	1.36	1.20	-0.53	0.36

Table B.9 Measured STI Results at the Auditorium (at S1).

Receiver	STI	STI-Female	STI-Male
R1	0.56	0.55	0.51
R2	0.55	0.53	0.49
R3	0.56	0.55	0.51
R4	0.55	0.53	0.49
R5	0.56	0.55	0.50
R6	0.56	0.55	0.50
R7	0.55	0.54	0.50
R8	0.55	0.54	0.50
R9	0.52	0.48	0.45
R10	0.52	0.49	0.45
R11	0.55	0.55	0.51
R12	0.54	0.54	0.49
R13	0.55	0.54	0.50
R14	0.53	0.51	0.47
R15	0.53	0.51	0.47
R16	0.52	0.50	0.46

Table B.10 Measured EDT Results at the Auditorium (at S2).

EDT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	2.16	1.71	1.32	1.39	1.26	1.12
R2	2.14	1.72	1.34	1.39	1.27	1.08
R3	2.17	1.72	1.32	1.35	1.23	1.12
R4	2.14	1.71	1.32	1.37	1.25	1.14
R5	1.84	1.71	1.51	1.30	1.20	1.14
R6	1.95	1.75	1.54	1.35	1.24	1.10
R7	1.45	1.64	1.57	1.32	1.24	1.11
R8	1.44	1.62	1.55	1.29	1.24	1.10
R9	1.42	1.63	1.55	1.35	1.21	1.10
R10	1.46	1.63	1.55	1.34	1.23	1.18
R11	1.60	1.51	1.56	1.33	1.31	1.11
R12	1.62	1.54	1.57	1.38	1.32	1.10
R13	1.59	1.52	1.57	1.37	1.36	1.12
R14	1.56	1.57	1.57	1.41	1.33	1.14
R15	1.55	1.54	1.61	1.38	1.39	1.06
R16	1.58	1.49	1.58	1.38	1.36	1.06

Table B.11 Measured RT Results at the Auditorium (at S2).

RT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.85	1.67	1.73	1.45	1.25	1.07
R2	2.05	1.66	1.72	1.44	1.25	1.06
R3	1.89	1.68	1.71	1.43	1.24	1.04
R4	1.98	1.67	1.72	1.42	1.23	1.04
R5	1.71	1.76	1.63	1.44	1.2	1.04
R6	1.65	1.77	1.62	1.41	1.22	1.06
R7	2.05	1.75	1.61	1.43	1.19	1.05
R8	1.97	1.76	1.64	1.44	1.20	1.05
R9	2.00	1.80	1.64	1.44	1.20	1.04
R10	2.15	1.80	1.64	1.45	1.21	1.03
R11	1.70	1.68	1.58	1.38	1.19	1.04
R12	2.86	1.71	1.58	1.37	1.19	1.05
R13	3.00	1.71	1.60	1.37	1.21	1.04
R14	2.00	1.68	1.61	1.37	1.17	1.01
R15	1.80	1.69	1.60	1.38	1.18	1.03
R16	2.62	1.73	1.62	1.41	1.19	1.03

Table B.12 Measured T_s Results at the Auditorium (at S2).

T_s [ms]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	142.66	87.00	73.33	97.00	106.66	97.33
R2	145.00	85.33	71.66	90.66	105.66	92.66
R3	144.33	91.00	72.00	94.66	105.33	100.66
R4	144.00	88.33	72.33	96.33	108.33	99.66
R5	103.66	90.00	75.33	94.66	104.33	89.33
R6	104.33	82.33	70.00	90.00	97.66	81.66
R7	126.66	91.00	76.00	95.00	73.66	69.00
R8	126.33	87.66	73.33	94.00	76.33	71.00
R9	125.33	93.33	75.33	95.33	71.66	69.33
R10	123.66	84.33	70.66	93.33	72.33	70.33
R11	139.00	89.33	77.33	97.33	57.66	55.00
R12	137.33	89.00	80.00	100.33	73.00	68.33
R13	140.00	90.00	80.00	99.00	59.00	56.66
R14	132.33	92.66	80.00	101.33	57.66	55.00
R15	134.33	90.00	80.66	102.33	62.66	59.66
R16	137.00	86.66	80.00	100.00	56.00	57.00

Table B.13 Measured D_{50} Results at the Auditorium (at S2).

D_{50} [-]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	0.48	0.58	0.52	0.35	0.29	0.28
R2	0.46	0.58	0.54	0.39	0.31	0.32
R3	0.51	0.56	0.51	0.34	0.30	0.30
R4	0.47	0.58	0.53	0.34	0.28	0.27
R5	0.54	0.50	0.52	0.37	0.29	0.35
R6	0.47	0.54	0.58	0.41	0.29	0.35
R7	0.26	0.50	0.56	0.39	0.48	0.51
R8	0.41	0.51	0.57	0.34	0.42	0.46
R9	0.37	0.50	0.55	0.39	0.48	0.50
R10	0.26	0.55	0.59	0.38	0.46	0.51
R11	0.36	0.48	0.49	0.34	0.59	0.61
R12	0.35	0.47	0.47	0.33	0.48	0.52
R13	0.27	0.48	0.48	0.37	0.60	0.61
R14	0.39	0.45	0.48	0.34	0.58	0.59
R15	0.33	0.48	0.49	0.36	0.57	0.55
R16	0.29	0.49	0.49	0.36	0.60	0.58

Table B.14 Measured C_{80} Results at the Auditorium (at S2).

C_{80} [dB]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.13	2.96	2.23	0.60	-0.56	-0.20
R2	0.83	2.83	2.46	1.00	-0.36	0.46
R3	1.73	2.40	2.2	0.60	-0.03	0.13
R4	1.03	2.80	2.36	0.50	-0.50	-0.36
R5	2.63	2.03	2.26	0.36	-0.20	0.80
R6	1.43	2.46	3.00	1.00	0.36	1.16
R7	-1.46	1.40	2.33	0.36	2.40	3.16
R8	0.60	1.33	2.43	0.56	2.23	2.86
R9	-0.03	1.23	2.06	0.56	2.46	3.26
R10	-1.10	2.16	2.86	0.80	2.26	3.06
R11	-1.10	1.20	2.63	1.06	3.83	4.50
R12	-1.13	1.13	2.23	0.40	2.40	3.26
R13	-2.23	1.33	2.23	0.93	3.66	4.23
R14	-0.33	1.10	2.20	0.23	3.73	4.63
R15	-1.63	1.43	1.90	0.80	3.26	3.83
R16	-2.00	1.63	2.33	1.00	3.96	4.63

Table B.15 Measured STI Results at the Auditorium (at S2).

Receiver	STI	STI-Female	STI-Male
R1	0.51	0.48	0.44
R2	0.51	0.49	0.45
R3	0.50	0.47	0.44
R4	0.51	0.47	0.44
R5	0.53	0.51	0.47
R6	0.54	0.51	0.47
R7	0.53	0.53	0.49
R8	0.53	0.54	0.50
R9	0.53	0.54	0.50
R10	0.54	0.54	0.50
R11	0.55	0.55	0.51
R12	0.54	0.53	0.49
R13	0.55	0.55	0.51
R14	0.55	0.55	0.51
R15	0.54	0.54	0.49
R16	0.54	0.55	0.51

Table B.16 Measured EDT Results at the Auditorium (at S3).

EDT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.35	1.38	1.38	1.48	1.30	1.11
R2	1.34	1.36	1.41	1.48	1.30	1.12
R3	1.27	1.38	1.41	1.50	1.34	1.10
R4	1.29	1.36	1.39	1.47	1.32	1.10
R5	1.29	1.37	1.39	1.47	1.27	1.09
R6	1.22	1.41	1.36	1.46	1.32	1.10
R7	1.30	1.36	1.38	1.48	1.33	1.13
R8	1.36	1.37	1.37	1.45	1.26	1.06
R9	1.17	1.14	1.28	1.15	1.19	1.05
R10	1.20	1.13	1.28	1.23	1.19	1.05
R11	1.24	1.25	1.44	1.32	1.23	1.04
R12	1.24	1.26	1.45	1.33	1.30	1.02
R13	1.24	1.26	1.46	1.36	1.27	1.10
R14	1.22	1.21	1.43	1.32	1.25	1.07
R15	1.21	1.24	1.49	1.44	1.33	1.09
R16	1.22	1.24	1.43	1.40	1.37	1.07

Table B.17 Measured RT Results at the Auditorium (at S3).

RT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.73	1.59	1.55	1.37	1.20	1.03
R2	1.76	1.59	1.55	1.37	1.20	1.03
R3	1.77	1.56	1.54	1.37	1.18	1.04
R4	1.79	1.58	1.54	1.37	1.18	1.03
R5	1.90	1.58	1.56	1.36	1.19	1.03
R6	1.73	1.60	1.55	1.37	1.19	1.02
R7	1.72	1.59	1.55	1.36	1.19	1.01
R8	1.76	1.57	1.55	1.35	1.19	1.01
R9	2.28	1.66	1.60	1.36	1.16	1.01
R10	2.08	1.65	1.60	1.37	1.16	1.02
R11	2.03	1.59	1.54	1.35	1.17	1.02
R12	1.88	1.58	1.56	1.35	1.17	1.01
R13	2.15	1.59	1.55	1.36	1.17	1.01
R14	2.01	1.60	1.52	1.35	1.18	1.00
R15	2.28	1.61	1.54	1.32	1.14	1.01
R16	2.13	1.60	1.53	1.33	1.15	1.03

Table B.18 Measured T_s Results at the Auditorium (at S3).

T_s [ms]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	74.33	90.33	46.00	92.00	91.33	87.00
R2	73.66	89.33	47.66	93.00	98.00	91.66
R3	78.00	90.33	45.66	90.66	98.00	88.33
R4	76.66	89.33	49.00	90.33	95.66	87.33
R5	76.66	90.00	47.00	88.00	93.00	87.00
R6	78.66	90.00	45.66	85.66	81.33	79.33
R7	76.00	89.33	46.66	89.33	83.66	83.66
R8	76.66	90.00	44.66	96.00	90.33	84.66
R9	88.33	68.00	84.66	70.00	72.00	76.66
R10	91.00	68.00	81.66	74.00	70.66	79.00
R11	75.00	59.33	71.00	59.66	64.33	74.00
R12	73.00	59.00	74.33	71.00	73.33	80.66
R13	72.66	59.33	72.33	64.33	64.33	78.33
R14	76.33	61.33	70.33	59.33	67.33	68.00
R15	70.33	57.33	71.00	70.33	88.33	65.00
R16	69.66	61.00	69.00	73.00	94.00	66.00

Table B.19 Measured D_{50} Results at the Auditorium (at S3).

D_{50} [-]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	0.56	0.51	0.61	0.40	0.35	0.35
R2	0.57	0.51	0.60	0.40	0.32	0.33
R3	0.55	0.51	0.62	0.42	0.30	0.33
R4	0.55	0.50	0.59	0.41	0.33	0.34
R5	0.55	0.52	0.61	0.43	0.32	0.32
R6	0.55	0.49	0.61	0.47	0.42	0.42
R7	0.56	0.48	0.61	0.45	0.36	0.38
R8	0.57	0.51	0.61	0.38	0.34	0.35
R9	0.38	0.51	0.45	0.45	0.46	0.53
R10	0.35	0.52	0.49	0.44	0.47	0.47
R11	0.63	0.62	0.57	0.55	0.53	0.53
R12	0.65	0.63	0.49	0.43	0.46	0.49
R13	0.62	0.65	0.56	0.52	0.54	0.54
R14	0.63	0.61	0.57	0.57	0.53	0.54
R15	0.62	0.63	0.55	0.45	0.42	0.50
R16	0.64	0.63	0.56	0.43	0.42	0.49

Table B.20 Measured C_{80} Results at the Auditorium (at S3).

C_{80} [dB]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.90	2.00	4.70	1.13	1.33	2.00
R2	2.06	2.00	4.40	1.03	0.40	1.36
R3	1.70	2.06	4.86	1.46	0.96	1.43
R4	1.70	2.03	4.50	1.30	1.13	1.83
R5	1.70	2.10	4.70	1.60	1.23	1.53
R6	1.70	1.80	5.03	2.20	2.20	2.76
R7	1.93	1.70	4.83	1.73	1.33	2.16
R8	1.86	2.03	4.73	0.80	1.16	2.00
R9	3.36	5.76	2.13	2.56	2.00	3.36
R10	2.86	5.70	2.33	2.23	2.10	2.90
R11	3.96	4.73	3.36	3.86	3.43	4.36
R12	4.60	4.96	2.36	1.90	1.96	3.83
R13	4.06	5.36	3.26	3.30	3.56	4.13
R14	4.00	4.16	3.53	4.10	3.16	4.06
R15	4.06	5.23	3.16	2.20	1.36	3.40
R16	4.5	5.36	3.46	2.16	1.36	3.26

Table B.21 Measured STI Results at the Auditorium (at S3).

Receiver	STI	STI-Female	STI-Male
R1	0.55	0.52	0.48
R2	0.54	0.51	0.47
R3	0.55	0.51	0.48
R4	0.54	0.51	0.47
R5	0.55	0.52	0.48
R6	0.56	0.54	0.50
R7	0.56	0.53	0.49
R8	0.54	0.51	0.47
R9	0.55	0.53	0.50
R10	0.55	0.52	0.49
R11	0.60	0.58	0.54
R12	0.57	0.55	0.51
R13	0.59	0.56	0.52
R14	0.60	0.58	0.54
R15	0.58	0.55	0.50
R16	0.57	0.53	0.49

APPENDIX C

ACC SIMULATION RESULTS

Table C.1 Simulated EDT Results at the ACC (at S1).

EDT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.46	0.88	0.78	0.87	0.91	0.74
R2	1.62	1.24	1.22	1.19	1.15	1.01
R3	1.45	0.95	0.86	0.89	0.85	0.74
R4	1.54	1.13	1.08	1.10	1.06	0.92
R5	1.47	0.98	0.93	0.97	0.93	0.83
R6	1.42	0.97	0.92	0.96	0.92	0.84
R7	1.38	0.98	0.90	0.91	0.85	0.76
R8	1.28	0.81	0.77	0.82	0.78	0.71

Table C.2 Simulated RT Results at the ACC (at S1).

RT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.37	1.01	1.00	0.99	0.92	0.84
R2	1.39	1.02	1.01	0.96	0.89	0.82
R3	1.36	1.03	1.03	1.01	0.91	0.81
R4	1.36	1.02	1.01	0.96	0.89	0.83
R5	1.34	1.04	1.01	0.99	0.90	0.82
R6	1.32	1.01	0.97	0.95	0.88	0.78
R7	1.30	0.99	0.96	0.93	0.88	0.79
R8	1.35	1.00	0.94	0.92	0.88	0.79

Table C.3 Simulated T_s Results at the ACC (at S1).

T_s [ms]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	82	46	41	46	48	39
R2	104	63	59	66	66	54
R3	89	58	54	57	55	48
R4	95	62	59	63	60	50
R5	95	66	62	65	60	53
R6	102	74	71	73	70	64
R7	94	68	63	64	60	54
R8	83	59	55	57	54	48

Table C.4 Simulated D_{50} Results at the ACC (at S1).

D_{50} [-]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	0.54	0.74	0.78	0.72	0.69	0.75
R2	0.39	0.59	0.62	0.56	0.54	0.61
R3	0.52	0.66	0.68	0.65	0.65	0.68
R4	0.47	0.62	0.63	0.60	0.61	0.67
R5	0.48	0.58	0.61	0.59	0.61	0.64
R6	0.39	0.47	0.49	0.48	0.49	0.51
R7	0.45	0.54	0.57	0.56	0.59	0.62
R8	0.51	0.62	0.66	0.64	0.65	0.69

Table C.5 Simulated C_{80} Results at the ACC (at S1).

C_{80} [dB]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	2.7	6.6	7.5	6.5	6.0	7.4
R2	0.3	3.8	4.1	3.4	3.3	4.7
R3	1.8	4.7	5.3	5.1	5.4	6.4
R4	1.2	3.9	4.1	3.7	4.1	5.3
R5	1.4	3.7	4.3	4.0	4.5	5.2
R6	0.9	3.1	3.6	3.2	3.5	4.2
R7	1.9	3.7	4.5	4.3	4.7	5.4
R8	3.3	5.6	6.1	5.6	5.8	6.6

Table C.6 Simulated STI Results at the ACC (at S1).

Receiver	STI	STI-Female	STI-Male
R1	0.62	0.63	0.60
R2	0.55	0.55	0.52
R3	0.60	0.61	0.58
R4	0.58	0.59	0.56
R5	0.57	0.57	0.54
R6	0.52	0.52	0.49
R7	0.55	0.56	0.52
R8	0.59	0.59	0.56

Table C.7 Simulated EDT Results at the ACC (at S2).

EDT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.53	1.27	1.38	1.19	1.09	0.95
R2	1.53	1.33	1.40	1.22	1.14	0.96
R3	1.56	1.27	1.23	1.19	1.14	1.01
R4	1.61	1.33	1.29	1.21	1.13	0.95
R5	1.54	1.19	1.10	1.10	1.07	0.92
R6	1.47	1.06	0.95	0.98	0.95	0.78
R7	1.42	1.08	0.93	0.96	0.95	0.80
R8	1.35	0.94	0.81	0.78	0.72	0.58

Table C.8 Simulated RT Results at the ACC (at S2).

RT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.37	1.00	0.90	0.92	0.91	0.81
R2	1.35	1.00	0.91	0.96	0.92	0.82
R3	1.34	0.99	0.88	0.94	0.90	0.80
R4	1.32	1.00	0.90	0.97	0.90	0.80
R5	1.36	0.99	0.86	0.92	0.92	0.81
R6	1.37	1.04	0.89	0.91	0.88	0.77
R7	1.41	1.05	0.93	0.93	0.87	0.76
R8	1.36	1.03	0.91	0.89	0.88	0.77

Table C.9 Simulated T_s Results at the ACC (at S2).

T_s [ms]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	110	63	54	61	62	47
R2	106	60	48	55	58	43
R3	114	71	62	66	64	52
R4	108	64	52	57	57	43
R5	109	70	60	64	62	52
R6	102	65	57	61	59	49
R7	99	64	54	57	56	47
R8	84	57	51	50	47	40

Table C.10 Simulated D_{50} Results at the ACC (at S2).

D_{50} [-]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	0.36	0.60	0.66	0.59	0.57	0.67
R2	0.36	0.60	0.68	0.62	0.58	0.68
R3	0.32	0.52	0.57	0.54	0.53	0.60
R4	0.37	0.59	0.67	0.61	0.60	0.69
R5	0.35	0.51	0.58	0.55	0.56	0.61
R6	0.39	0.56	0.60	0.57	0.58	0.64
R7	0.40	0.57	0.63	0.60	0.60	0.65
R8	0.55	0.66	0.70	0.70	0.72	0.76

Table C.11 Simulated C_{80} Results at the ACC (at S2).

C_{80} [dB]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	-0.5	3.3	4.4	3.6	3.3	5.3
R2	-0.1	3.9	5.0	4.4	4.2	6.1
R3	-1.4	1.8	2.7	2.5	3.0	4.3
R4	-0.2	3.3	4.4	4	4.1	6.0
R5	-0.5	2.5	3.8	3.4	3.7	5.1
R6	0.7	3.9	4.7	4.2	4.4	5.7
R7	0.7	3.7	5.0	4.6	4.6	5.9
R8	2.4	4.7	5.7	6	6.5	7.7

Table C.12 Simulated STI Results at the ACC (at S2).

Receiver	STI	STI-Female	STI-Male
R1	0.55	0.56	0.53
R2	0.57	0.58	0.55
R3	0.54	0.55	0.51
R4	0.57	0.59	0.55
R5	0.54	0.55	0.51
R6	0.54	0.55	0.51
R7	0.55	0.56	0.52
R8	0.61	0.61	0.57

APPENDIX D

AUDITORIUM SIMULATION RESULTS

Table D.1 Simulated EDT Results at the Auditorium (at S1).

EDT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	2.30	2.24	2.33	2.14	2.00	2.01
R2	2.17	1.78	1.77	1.59	1.51	1.34
R3	1.62	1.36	1.33	1.40	1.17	1.07
R4	1.87	1.62	1.72	1.64	1.27	1.15
R5	1.94	1.69	1.68	1.52	1.61	1.39
R6	2.13	1.74	1.76	1.60	1.57	1.36
R7	1.85	1.60	1.66	1.66	1.47	1.47
R8	1.94	1.65	1.80	1.69	1.47	1.40
R9	1.74	1.38	1.65	1.67	1.33	1.39
R10	1.46	1.19	1.18	1.27	0.93	0.82
R11	1.64	1.36	1.38	1.28	1.10	0.98
R12	1.36	1.15	1.14	1.14	0.93	0.86
R13	1.54	1.27	1.39	1.34	1.03	1.00
R14	1.56	1.29	1.24	1.25	1.02	0.94
R15	1.49	1.02	1.13	1.14	0.94	0.84
R16	1.34	1.19	1.18	1.21	0.92	0.89

Table D.2 Simulated RT Results at the Auditorium (at S1).

RT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.80	1.76	1.49	1.38	1.18	1.21
R2	1.76	1.71	1.53	1.45	1.19	1.18
R3	1.77	1.67	1.44	1.37	1.22	1.12
R4	1.84	1.65	1.45	1.35	1.17	1.14
R5	1.73	1.72	1.45	1.35	1.16	1.12
R6	1.74	1.73	1.47	1.36	1.18	1.14
R7	1.73	1.66	1.47	1.39	1.20	1.13
R8	1.74	1.63	1.46	1.37	1.18	1.13
R9	1.75	1.60	1.47	1.38	1.19	1.19
R10	1.70	1.58	1.39	1.27	1.19	1.12
R11	1.71	1.72	1.48	1.40	1.21	1.16
R12	1.69	1.63	1.46	1.40	1.16	1.15
R13	1.85	1.72	1.58	1.46	1.18	1.18
R14	1.75	1.90	1.79	1.80	1.19	1.29
R15	1.78	1.77	1.55	1.50	1.15	1.14
R16	1.91	1.72	1.51	1.39	1.10	1.10

Table D.3 Simulated T_s Results at the Auditorium (at S1).

T_s [ms]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	100	76	72	69	61	48
R2	109	79	80	77	70	60
R3	96	75	78	74	64	54
R4	90	73	71	67	58	46
R5	102	84	79	74	61	55
R6	110	81	80	77	69	59
R7	97	73	81	75	61	55
R8	116	88	94	86	65	60
R9	103	69	76	74	69	53
R10	78	67	65	66	54	48
R11	100	70	75	68	63	53
R12	83	68	70	68	59	55
R13	89	67	76	74	59	59
R14	95	72	78	76	65	60
R15	87	63	72	72	62	58
R16	80	69	72	72	55	57

Table D.4 Simulated D_{50} Results at the Auditorium (at S1).

D_{50} [-]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	0.55	0.63	0.65	0.64	0.66	0.72
R2	0.49	0.60	0.58	0.58	0.58	0.63
R3	0.45	0.52	0.50	0.52	0.57	0.61
R4	0.54	0.58	0.60	0.62	0.65	0.70
R5	0.44	0.52	0.53	0.53	0.60	0.61
R6	0.48	0.60	0.60	0.60	0.61	0.66
R7	0.45	0.55	0.50	0.53	0.59	0.63
R8	0.37	0.45	0.45	0.47	0.55	0.58
R9	0.47	0.65	0.62	0.61	0.56	0.70
R10	0.65	0.67	0.69	0.66	0.72	0.75
R11	0.41	0.56	0.53	0.56	0.56	0.63
R12	0.53	0.60	0.59	0.59	0.64	0.65
R13	0.53	0.63	0.58	0.58	0.66	0.65
R14	0.44	0.52	0.47	0.49	0.53	0.55
R15	0.53	0.63	0.57	0.56	0.61	0.62
R16	0.55	0.59	0.55	0.55	0.65	0.62

Table D.5 Simulated C_{80} Results at the Auditorium (at S1).

C_{80} [dB]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.0	2.8	3.1	3.4	3.6	5.0
R2	0.3	2.5	2.3	2.5	2.9	3.6
R3	1.9	3.4	2.7	2.8	3.6	4.4
R4	2.1	3.1	3.2	3.4	4.4	5.1
R5	0.9	2.2	2.3	2.6	3.7	4.0
R6	0.1	2.2	2.2	2.4	2.9	3.6
R7	0.1	1.6	0.8	1.5	2.6	3.4
R8	-0.4	1.8	1.1	1.9	3.3	3.8
R9	1.1	3.7	3.2	3.0	3.0	4.8
R10	3.9	4.2	4.6	4.0	5.9	6.0
R11	1.4	3.6	3.0	3.8	3.9	5.2
R12	3.1	4.0	3.9	3.8	5.1	5.1
R13	1.9	3.3	2.9	2.8	4.6	4.3
R14	2.2	3.9	3.4	3.4	4.4	4.8
R15	2.1	3.9	3.1	2.9	3.9	4.2
R16	2.8	2.7	2.9	2.4	4.5	4.1

Table D.6 Simulated STI Results at the Auditorium (at S1).

Receiver	STI	STI-Female	STI-Male
R1	0.47	0.44	0.39
R2	0.42	0.40	0.35
R3	0.41	0.40	0.35
R4	0.42	0.39	0.34
R5	0.45	0.43	0.38
R6	0.42	0.40	0.35
R7	0.45	0.43	0.38
R8	0.40	0.38	0.34
R9	0.42	0.39	0.34
R10	0.46	0.43	0.39
R11	0.42	0.40	0.35
R12	0.44	0.42	0.37
R13	0.42	0.39	0.34
R14	0.39	0.36	0.31
R15	0.42	0.39	0.34
R16	0.41	0.38	0.33

Table D.7 Simulated EDT Results at the Auditorium (at S2).

EDT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	2.33	1.80	1.83	1.57	1.46	1.28
R2	2.19	1.60	1.72	1.52	1.34	1.22
R3	2.17	1.73	1.90	1.71	1.48	1.45
R4	1.91	1.67	1.76	1.65	1.36	1.19
R5	2.12	1.92	1.82	1.68	1.77	1.52
R6	2.14	1.72	1.80	1.62	1.58	1.52
R7	1.99	1.66	1.77	1.69	1.65	1.58
R8	1.64	1.23	1.31	1.18	1.13	0.96
R9	2.02	1.49	1.55	1.49	1.53	1.23
R10	1.79	1.47	1.45	1.43	1.03	1.06
R11	1.64	1.38	1.27	1.18	0.96	0.88
R12	1.73	1.52	1.36	1.25	1.12	0.96
R13	1.64	1.49	1.37	1.22	1.10	0.97
R14	1.82	1.47	1.38	1.32	1.05	0.96
R15	1.60	1.22	1.23	1.12	0.94	0.82
R16	1.52	1.34	1.17	1.07	0.98	0.86

Table D.8 Simulated RT Results at the Auditorium (at S2).

RT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.72	1.71	1.47	1.40	1.23	1.19
R2	1.76	1.72	1.47	1.40	1.22	1.21
R3	1.83	1.67	1.44	1.37	1.18	1.16
R4	1.87	1.67	1.44	1.39	1.15	1.12
R5	1.71	1.74	1.44	1.37	1.18	1.14
R6	1.74	1.64	1.43	1.36	1.16	1.13
R7	1.72	1.70	1.41	1.31	1.18	1.10
R8	1.73	1.61	1.42	1.32	1.20	1.11
R9	1.72	1.63	1.41	1.31	1.13	1.10
R10	1.72	1.65	1.40	1.27	1.14	1.08
R11	1.74	1.69	1.47	1.35	1.19	1.14
R12	1.74	1.70	1.47	1.39	1.20	1.16
R13	1.73	1.67	1.50	1.34	1.18	1.14
R14	1.75	1.67	1.49	1.45	1.26	1.21
R15	1.73	1.60	1.44	1.37	1.19	1.14
R16	1.64	1.68	1.46	1.37	1.19	1.15

Table D.9 Simulated T_s Results at the Auditorium (at S2).

T_s [ms]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	115	83	75	64	48	40
R2	114	78	76	69	57	45
R3	122	89	92	83	69	53
R4	95	81	76	70	60	46
R5	118	103	90	81	64	58
R6	121	95	91	82	64	51
R7	120	96	97	89	64	57
R8	96	72	73	67	60	52
R9	102	64	70	68	68	50
R10	92	82	74	74	57	52
R11	99	76	74	67	63	53
R12	97	73	73	66	59	52
R13	107	79	83	76	64	62
R14	108	76	79	72	64	57
R15	100	72	77	72	64	59
R16	79	64	64	61	49	48

Table D.10 Simulated D_{50} Results at the Auditorium (at S2).

D_{50} [-]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	0.49	0.59	0.64	0.68	0.74	0.79
R2	0.45	0.57	0.60	0.61	0.64	0.72
R3	0.39	0.46	0.46	0.47	0.53	0.63
R4	0.48	0.50	0.54	0.55	0.59	0.66
R5	0.41	0.45	0.49	0.51	0.61	0.61
R6	0.39	0.43	0.47	0.48	0.58	0.65
R7	0.37	0.42	0.43	0.45	0.59	0.62
R8	0.44	0.54	0.54	0.56	0.59	0.63
R9	0.52	0.66	0.62	0.60	0.61	0.69
R10	0.54	0.53	0.58	0.56	0.65	0.67
R11	0.34	0.49	0.48	0.51	0.47	0.56
R12	0.49	0.60	0.59	0.61	0.61	0.66
R13	0.38	0.52	0.49	0.51	0.57	0.56
R14	0.38	0.53	0.50	0.54	0.54	0.57
R15	0.45	0.59	0.55	0.57	0.57	0.61
R16	0.56	0.62	0.62	0.61	0.70	0.68

Table D.11 Simulated C_{80} Results at the Auditorium (at S2).

C_{80} [dB]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	0.4	2.6	3.2	4.3	5.4	6.8
R2	0.9	3.4	3.5	4.2	4.6	6.2
R3	0.2	2.3	2.0	2.7	3.1	4.8
R4	3.0	3.5	3.6	4.1	5.4	6.5
R5	-0.5	0.2	1.0	1.9	3.3	3.7
R6	-0.1	1.2	1.4	2.2	3.5	4.8
R7	-0.4	1.0	0.6	1.4	3.5	4.1
R8	2.7	4.4	4.1	4.5	4.9	5.9
R9	1.8	4.5	3.6	3.5	3.4	5.3
R10	2.7	3.0	3.6	3.4	5.3	5.5
R11	2.3	4.0	3.9	4.6	4.6	6.1
R12	2.1	4.1	3.9	4.5	4.7	5.7
R13	0.3	2.7	2.3	2.6	3.8	3.9
R14	1.5	4.1	3.4	4.1	4.5	5.3
R15	1.5	4.3	3.6	4.2	4.4	5.3
R16	3.9	4.8	4.8	4.9	6.6	6.4

Table D.12 Simulated STI Results at the Auditorium (at S2).

Receiver	STI	STI-Female	STI-Male
R1	0.45	0.43	0.38
R2	0.42	0.40	0.35
R3	0.37	0.34	0.29
R4	0.38	0.35	0.30
R5	0.41	0.39	0.34
R6	0.40	0.38	0.33
R7	0.39	0.37	0.32
R8	0.42	0.40	0.35
R9	0.41	0.38	0.33
R10	0.40	0.37	0.32
R11	0.39	0.36	0.32
R12	0.39	0.36	0.31
R13	0.34	0.31	0.27
R14	0.35	0.32	0.27
R15	0.36	0.33	0.28
R16	0.40	0.36	0.31

Table D.13 Simulated EDT Results at the Auditorium (at S3).

EDT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	2.11	1.72	1.75	1.56	1.48	1.42
R2	2.21	1.78	1.80	1.61	1.48	1.35
R3	1.62	1.27	1.18	1.18	1.14	1.00
R4	1.72	1.15	1.24	1.20	1.24	0.98
R5	2.28	1.85	2.15	1.78	1.64	1.29
R6	2.35	1.82	1.85	1.66	1.53	1.40
R7	2.52	1.83	1.82	1.51	1.56	1.21
R8	2.25	1.96	1.95	1.72	1.64	1.44
R9	1.95	2.07	2.09	1.94	1.46	1.67
R10	1.38	1.31	1.22	1.38	1.03	0.97
R11	1.63	1.34	1.32	1.23	1.20	1.04
R12	1.35	1.21	1.18	1.22	0.97	0.99
R13	1.67	1.43	1.39	1.35	1.19	1.18
R14	1.47	1.23	1.26	1.24	1.06	1.03
R15	1.58	1.26	1.25	1.26	1.08	1.05
R16	1.69	1.23	1.23	1.25	1.08	1.10

Table D.14 Simulated RT Results at the Auditorium (at S3).

RT [s]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	1.73	1.69	1.45	1.34	1.20	1.12
R2	1.72	1.63	1.42	1.35	1.22	1.12
R3	1.73	1.63	1.43	1.35	1.22	1.12
R4	1.77	1.65	1.40	1.33	1.23	1.11
R5	1.74	1.66	1.46	1.36	1.23	1.15
R6	1.74	1.60	1.45	1.34	1.24	1.14
R7	1.76	1.67	1.49	1.41	1.29	1.18
R8	1.72	1.66	1.46	1.39	1.25	1.17
R9	1.82	1.61	1.43	1.38	1.25	1.16
R10	1.67	1.57	1.43	1.34	1.26	1.14
R11	1.77	1.66	1.44	1.38	1.18	1.11
R12	1.74	1.57	1.39	1.31	1.19	1.07
R13	1.85	1.58	1.41	1.31	1.21	1.08
R14	1.70	1.65	1.44	1.44	1.18	1.14
R15	1.67	1.53	1.39	1.29	1.19	1.07
R16	1.65	1.58	1.46	1.39	1.22	1.18

Table D.15 Simulated T_s Results at the Auditorium (at S3).

T_s [ms]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	112	83	81	78	69	59
R2	111	81	83	80	71	61
R3	97	69	73	71	72	60
R4	93	74	72	73	71	58
R5	46	32	33	31	24	22
R6	70	51	62	61	46	45
R7	73	43	48	47	42	36
R8	96	59	68	67	63	52
R9	91	77	82	82	60	54
R10	70	64	62	67	55	51
R11	101	73	76	70	65	56
R12	76	65	70	72	57	58
R13	103	83	87	85	69	71
R14	95	73	82	79	68	65
R15	82	67	74	76	60	62
R16	73	60	67	70	51	57

Table D.16 Simulated D_{50} Results at the Auditorium (at S3).

D_{50} [-]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	0.46	0.60	0.59	0.59	0.60	0.66
R2	0.47	0.58	0.57	0.56	0.57	0.62
R3	0.48	0.61	0.56	0.57	0.53	0.60
R4	0.55	0.60	0.61	0.59	0.59	0.66
R5	0.78	0.85	0.83	0.83	0.87	0.88
R6	0.67	0.74	0.69	0.68	0.74	0.74
R7	0.69	0.82	0.79	0.78	0.79	0.82
R8	0.52	0.67	0.62	0.60	0.60	0.65
R9	0.58	0.63	0.59	0.58	0.68	0.70
R10	0.70	0.74	0.72	0.69	0.73	0.76
R11	0.43	0.56	0.54	0.56	0.58	0.63
R12	0.60	0.64	0.61	0.59	0.66	0.66
R13	0.48	0.54	0.50	0.51	0.60	0.57
R14	0.46	0.58	0.51	0.54	0.57	0.59
R15	0.60	0.63	0.59	0.57	0.67	0.64
R16	0.66	0.66	0.62	0.58	0.73	0.66

Table D.17 Simulated C_{80} Results at the Auditorium (at S3).

C_{80} [dB]	Frequency [Hz]					
Receiver	125	250	500	1000	2000	4000
R1	-0.2	2.0	2.1	2.4	2.8	3.8
R2	0.4	2.6	2.3	2.4	2.9	3.7
R3	1.8	3.6	3.2	3.0	3.1	4.0
R4	1.9	2.7	3.0	2.7	3.2	4.3
R5	5.7	7.7	7.1	7.4	8.4	8.9
R6	3.6	5.2	4.2	4.0	5.6	5.5
R7	4.0	7.2	6.3	6.4	6.6	7.6
R8	1.6	4.4	3.7	3.6	3.8	4.9
R9	2.3	3.0	2.5	2.3	4.5	4.9
R10	5.6	5.9	5.9	5.0	6.7	6.9
R11	0.2	2.1	1.8	2.2	2.7	3.4
R12	3.3	3.7	3.4	2.9	4.7	4.3
R13	1.4	2.3	2.3	2.4	4.1	3.6
R14	0.9	2.3	1.6	1.9	2.9	3.1
R15	2.9	3.3	3.0	2.5	4.7	3.9
R16	3.3	3.8	3.6	2.9	5.6	4.3

Table D.18 Simulated STI Results at the Auditorium (at S3).

Receiver	STI	STI-Female	STI-Male
R1	0.42	0.40	0.35
R2	0.41	0.39	0.34
R3	0.41	0.39	0.34
R4	0.39	0.36	0.31
R5	0.65	0.63	0.58
R6	0.50	0.48	0.43
R7	0.54	0.52	0.46
R8	0.45	0.42	0.37
R9	0.43	0.41	0.36
R10	0.45	0.42	0.38
R11	0.42	0.40	0.35
R12	0.45	0.42	0.37
R13	0.38	0.35	0.31
R14	0.38	0.36	0.31
R15	0.42	0.39	0.34
R16	0.44	0.40	0.35