AN APPROACH ON DETERMINING OPTIMUM ACOUSTIC CONDITIONS FOR TURKISH CLASSICAL MUSIC

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ABSTRACT

AN APPROACH ON DETERMINING OPTIMUM ACOUSTIC CONDITIONS FOR TURKISH CLASSICAL MUSIC

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From past to present, performance spaces are being designed in order to provide better listening conditions according to their function. Rooms for classical music have different qualities in comparison to rooms for speech, for instance. However, while acoustic design regarding western-originated performances have been present for centuries, no such attempt has been made for Turkish classical music (TCM).

This study aims to search for possible acoustic conditions that would complement the characteristics of TCM and try to improve the overall quality of spaces where TCM may be performed. After an in depth analysis of room acoustics parameters, acoustic evaluation systems and characteristics of TCM, spectral analyses are done for western classical music, opera and TCM, in order to understand the distinctions between the three. Afterwards, three different performance spaces with different qualities are modelled digitally in the 3D environment which were then transferred into Odeon room acoustics software, where anechoic audio recordings of TCM are auralised.

A listening test is made with the auralisations for the correlation of objective and subjective acoustic parameters, and an acoustic evaluation survey is conducted to the listeners. Afterwards, a virtual room is modelled with conditions close to an anechoic room, where various changes are made in order to achieve better conditions for TCM through trial and error. Finally, four alternatives with the best conditions are taken into a listening test. The results are believed to yield close-to-optimum acoustic conditions for TCM, and may be used for in depth future studies.

Keywords: Turkish Classical Music, Room Acoustics, Acoustic Evaluation, Acoustic Design

ÖZ

KLASİK TÜRK MÜZİĞİ İÇİN OPTİMUM AKUSTİK KOŞULLARIN BELİRLENMESİ ÜZERİNE BİR YAKLAŞIM

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Performans mekanları, geçmişten günümüze fonksiyonları doğrultusunda dinleyiciye daha iyi koşullar sağlayacak şekilde tasarlanmaktadır. Örneğin, klasik müzik için tasarlanan mekanlar konuşma için tasarlanmış mekanlara göre farklı koşullara sahiptir. Ancak, sözü geçen mekanlarda akustik tasarım batı doğuşlu performans türleri için yüzyıllardır süregelse de, Klasik Türk Müziği (KTM) için günümüze kadar bu alanda bir çalışma yapılmamıştır.

Bu çalışmada KTM'nin karakteristik özelliklerini ortaya çıkaracak ve KTM icra edilebilecek mekanların bütüncül akustik kalitesini iyileştirecek muhtemel akustik koşulların arayışına girilmiştir. Hacim akustiği parametreleri, akustik değerlendirme sistemleri ve KTM'nin yapısal özellikleri hakkında derinlemesine bir araştırmanın ardından batı klasik müziği, opera ve KTM arasındaki farklılıkları gösterecek spektrum analizleri yapılmıştır. Sonrasında, farklı özelliklere sahip üç performans mekanı 3 boyutlu ortamda modellenerek anekoik KTM ses kayıtları bu mekanlarda Odeon programı kullanılarak oralize edilmiştir.

Öznel ve nesnel akustik parametreler arasındaki bağlantıyı kurabilmek adına, yapılan oralizasyonlar ile bir dinleme testi gerçekleştirilmiş ve dinleyicilere akustik değerlendirme yapacakları bir anket sunulmuştur. Daha sonra anekoik oda koşullarına yakın olacak şekilde bir sanal oda modellenmiş ve KTM için daha iyi koşullar elde edebilmek adına oda üzerinde deneme-yanılma yolu ile çeşitli değişiklikler yapılmıştır. Son olarak, yapılan denemeler içerisinde en iyi koşullara sahip olduğu düşünülen dört alternatif, bir dinleme testine sokulmuştur. Elde edilen sonuçların KTM için optimuma yakın koşullar sağladığı ve bu sonuçların gelecek çalışmalar için kullanılabileceği düşünülmektedir.

Anahtar Kelimeler: Klasik Türk Müziği, Hacim Akustiği, Akustik Değerlendirme, Akustik Tasarım

To all those in life whose stories remain unfinished, and melodies unwritten;

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TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF ABBREVIATIONS

ABBREVIATIONS

TCM: Turkish classical music

RT: Reverberation time

T_{30}: Reverberation time in 30 milliseconds

EDT: Early decay time

C_{80}: Clarity

D_{50}: Distinctness

BR: Bass ratio

SPL: Sound pressure level

LF_{80}: Early lateral energy fraction

LG_{80}: Late arriving lateral energy

Ts: Central time

STI: Speech transmission index

SPL(A): Sum of weighted sound pressure level

Hz: Hertz

dB: Decibel

TRT: Turkish Radio and Television

CHAPTER 1

INTRODUCTION

This chapter presents information based on previously done research in the regarding field and provides an introduction to the study. After a brief background summary, a motivation and argument has been presented for this research, followed by the aim and objectives of the research. The contributions of the proposed study are also presented after the aim and objectives. Finally, a brief layout of the contents in this thesis is introduced in the disposition section.

1.1. Argument

Auditory perception is just as important as visual perception when it comes to human comfort. For years, the study of architectural acoustics aims to improve acoustic comfort both in outdoor and indoor spaces. While building acoustics focuses essentially on reducing unwanted noise in order to provide acoustic comfort, the main purpose room acoustics is to make sure that the sound reaches all the listeners with the most suitable conditions in rooms of which the main purpose is listening.

Performance spaces are being used almost as early as the history of mankind. From ancient Greek theaters to Renaissance cathedrals, man has always struggled to design special spaces for rituals, dances, drama or music. While said spaces were being designed with acoustics in mind, it was not up until the end of the 19^{th} century where acoustics had started to be studied as a science. As the research on acoustics has progressed, new discoveries have been made such as objective acoustic parameters, where one can measure certain aspects of spaces such as reverberation time, early decay time or clarity index, in order to distinguish good and bad qualities of a room.

However, researchers have started to realize that acoustics could not be evaluated solely by using objective parameters, due to human perception being a subjective element, hence the subjective acoustic parameters were found in order to see the relationship between the objective qualities of a room and the reaction of a listener.

The study of room acoustics has led to an advancement on principles and technologies in the design of performance spaces. Performance spaces that were being built had started to become more and more successful in terms of acoustic quality. Although, these improvements were more significant in the west, mainly focusing on western art forms such as classical music, opera or drama. Today, most concert halls in Turkey are designed to be multi-purpose and provide average acoustic conditions to abide with a wide range of performances. Although some may have slightly better conditions in terms of room acoustics, few of them specialize to achieve specific conditions for specific types of music, mainly western classical music. There are also examples of concert venues striving to obtain preferable acoustic conditions for rock and pop concerts, however, no efforts have been made in order to analyze and determine the best acoustic conditions for Turkish classical music (TCM), which is different than western classical music in terms of instruments, modes (makam), measures and monophony.

1.2. Aim and Objectives

This thesis aims to investigate optimum acoustic conditions for TCM by determining favorable objective and subjective parameters that are suitable in order to design performance spaces that specialize for TCM which would enhance the listeners' general experience while listening to a TCM performance. The primary concern in the first place is to examine the characteristics of TCM to find out its similarities and differences between other types of music, such as the instruments that are used, the traditional spaces where TCM has used to be played, or the size of a traditional TCM orchestra. This brings out the possibility to figure out the objective and subjective acoustic parameters that are needed for optimum acoustic quality. Afterwards, the parameters that are believed to be effective to create a successful performance space for TCM need to be tested for more accurate results. This is only possible to a certain point, since optimum parameters for performance halls require evaluating a feasible amount of rooms to be able to determine a standard quality. This problem may be counteracted by changing the parameters of a certain room and experimenting through a process of trial and error. After a reasonable amount of scenarios have been tested, the optimum conditions for TCM could be figured out.

1.3. Materials and Method

In order for this study to be executed, firstly an anechoic recording of a TCM performance is required. This is done in an anechoic room with musicians playing various pieces. After this process is done, the recorded performances will be transferred into Odeon room acoustics software to be simulated and auralised.

Three different performance spaces are modelled which have different sizes, forms and acoustic parameters. The anechoic recordings are then auralised as mentioned before. The auralisations are used for a listening test, conducted to professionals who are experienced in Turkish music.

Deriving from the results of the listening test, the room with the best conditions is selected. The next step is to get closer to optimum conditions for TCM. This is done by using a model of a room which has the properties of an anechoic chamber. The model is altered to generate various different conditions that have different acoustic parameters. Anechoic recordings are auralised in these different room scenarios to see which parameters yield the best results. A second listening test is conducted with the auralisations from said scenarios and objective acoustic parameters are correlated with subjective parameters for more accurate results.

1.4. Contribution

Research has been done in the field of room acoustics since the end of the 19^{th} century that focuses on performance spaces and how to improve them. Optimum acoustic parameters for classical music, opera, theater and speech have become well acknowledged today. However, the information regarding optimum conditions for TCM is very limited, even to this day. This study aims to be a guiding light for future studies regarding TCM. It is considered that the study will be the first step for determining a standard for TCM acoustic conditions, and even bring up a new research area that focuses on TCM exclusively.

1.5. Disposition

This thesis consists of five chapters. In the first chapter, a brief introduction has been made along with the argument behind the research and aim and objectives that it possesses. The chapter is then followed by the contributions of the research and the disposition of the whole study.

The second chapter presents previous work in the related field and a discussion about conducted studies. After giving brief information in the field of architectural acoustics, studies concerning objective and subjective acoustic parameters are introduced in detail and acoustic evaluation methods are presented. Afterwards, a brief information about Turkish classical music is given, which talks about the history of TCM along with its musical characteristics and instruments.

The third chapter consists of analyses of song samples from western classical music, opera and TCM. The songs are analyzed in terms of frequency spectra, musical structure and dominant elements. The analyses are then compared with each other in order to understand the similarities and differences between each other. Later, inferences are made regarding the acoustic properties of TCM such as the optimum reverberation times, early decay times and bass ratio.

In the fourth chapter, the materials and method of this study is given. First, three performance spaces are modelled in Odeon room acoustics software and acoustic measurements are made. Afterwards, anechoic TCM recordings are auralised to be taken into a listening test. After the listening test, various attempts are made in a virtual box trying to find out optimum acoustic conditions for TCM. Ultimately, a second listening test is conducted from the outputs.

The fifth chapter consists of the results that are obtained in the study. Since the study has yet to be conducted, there are no results available at the moment. However, it is planned to achieve a better understanding in terms of perceptual effects and their relationship between objective aspects of said spaces.

The final chapter which is the conclusion chapter, provides the reader with a brief summary of the study. At the end of this chapter, the limitations for this study are discussed and suggestions have been proposed for future studies.

CHAPTER 2

LITERATURE REVIEW

The second chapter lays out information gathered from earlier literature that is relevant to the topic. The acquired data is presented under five sections. The first section talks about basic principles of architectural acoustics to provide background information to the reader. Afterwards, a second section about room acoustic parameters is introduced. Objective and subjective parameters that are used in this thesis are explained in detail and recommended optimum values are given. The third section informs the reader about the design of performance spaces. Design criteria such as form, size and function are discussed followed by examples of acoustic evaluation systems. Next is the fourth section that focuses on Turkish classical music (TCM). Starting with the history of TCM, the section investigates the main aspects and characteristics of TCM and informs the reader about the types of instruments that are commonly used in TCM along with the traditional performance spaces that were used for TCM in the Ottoman period. The fifth and final section discusses a brief summary of all the literature and points out inadequacies and lack of research on the subject.

2.1. Architectural Acoustics

After coming out of its source, sound travels through air and it is similar to how light travels considering they both travel in straight lines and their intensity can diminish in accordance to the distance travelled. However, while light has an imperceptible vibration, sound is actually the vibration of matter. Thus, the properties of sound are used in architecture, which creates the term of architectural acoustics (Elson, 1921). In the words of Mommertz (2009), "acoustics is derived from the Greek word ακουειν (akouein), which means "to hear", and is the branch of science that deals with sound, including its generation, transmission, analysis and perception.". Architectural acoustics has been around since more than 2500 years ago, when Pythagoras examined musical relationships and Vitruvius worked on the acoustic design of amphitheaters. In the modern era, acoustics became a scientific field of studies and in the 20th century, room acoustics and building acoustics have been introduced to the field of this science (Barron, 1993).

Hearing is a very complex mechanism for humans in terms of sensing acoustic signals. The average hearing frequency range of a human is between 20Hz and 20000Hz (Kleiner, 2012). According to Kleiner, higher frequencies and binaural hearing allow for good directional hearing. Different frequencies, sound levels and timbres have different effects on the human brain activity. Although "good acoustics" mostly refer to well-designed concert halls or ancient theatres, every closed space has an acoustic dimension (Kuttruff, 2006). As Mommertz (2009) puts it, "Hearing and understanding are fundamental prerequisites for communication, and the acoustic feedback of an interior for speech or music is essential; infiltrating noise is disturbing – and can even be unhealthy." Usually, humans are not aware of the acoustic quality of a certain space. However, when difficulties in perception -such as not being able to understand speech or being in a noisy office environment- occur, they tend to get disturbed and this usually has mental or even physiological consequences.

Architectural acoustics can be divided into two main categories: building acoustics and room acoustics. Building acoustics deals with sound insulation and noise control. Its primary purpose is to prevent unwanted sounds to travel and spread within the building, whereas room acoustics is more concerned with how the propagation of sound affects the listener's perception in a certain room (Beranek, 2004). The perception of the listener depends on the properties of sound fields. They can be related directly to the energy levels as well as the volume of the space in which the sound is distributed, just as much as they can be time-dependent (Long, 2006).

According to Mommertz (2009), building acoustics deals with sound propagation inside a building whether it should be from room to room, from outside to inside or even from inside to outside. It is concerned with the prevention of unwanted acoustic disturbance; or in other words, noise (Long, 2006).

Noise control can be done by proper application of acoustic insulation and in order to achieve that, one must know the acoustic properties of building materials (Mommertz, 2009). Large and flat materials work well with absorbing lower-frequency sounds while porous materials are highly efficient with high-frequency sounds (Long, 2006). It is usually recommended that a balanced combination of both materials should be used in order to obtain satisfactory noise control. It can be said that there are two main types of sound propagation: airborne and structure-borne sound propagation (Kleiner, 2012).

If a sound is created in a room, this causes the surrounding elements to vibrate. These vibrations are then transmitted to a bordering room, leading to an airborne sound. Structure-borne sounds on the other hand are sounds when structural elements are vibrated by means of direct mechanical actions such as walking on the floor or operating machinery. This may be avoided by using absorbent materials where there is direct contact with the sound source causing the noise (Mommertz, 2009).

We can understand that hearing experience does not rely on sound propagation alone, but the design and perception of space, as well. Therefore, room acoustics should deal with acoustic issues as well as sensible design (Mommertz, 2009). The study of room acoustics involves many other cases such as architecture, art, music, physics, engineering and psychology (Kleiner, 2012). We can examine room acoustics in two categories: technical room acoustics and psychological room acoustics. Technical room acoustics can be divided into three subcategories as well: geometrical, statistical and wave theory room acoustics. As Kleiner suggests, all of these approaches need to be fully understood to be able to successfully design the acoustic conditions in spaces.

2.2. Room Acoustic Parameters

Room acoustics deals with the satisfactory perception of a listener in a certain space, as mentioned earlier. Each listener in an audience may have their individual subjective experience in a space, and these subjective assessments determine whether or not the audience is satisfied in said spaces in terms of acoustic quality. However, the use of these subjective opinions in a scientific point of view is only possible by converting the subjective outputs into objective parameters (Kara, 2009). Experiments done in existent and simulated sound environments have resulted in the development of objective acoustic parameters that correlate with relevant subjective opinions. These parameters have been accepted as identifiers for perceiving acoustic quality and have become standardized in most cases (Yüksel Can, 2012).

When examining a closed space, evaluation parameters can be broken down into two main categories, one being the objective parameters which depend on individual perception and the other being the measurable subjective parameters (Beranek, 2004).

2.2.1. Objective Acoustic Parameters

Subjective parameters in room acoustics are parameters that have absolute numerical values, in contrary to subjective parameters. While previous research has presented recommended values for these parameters, said values may differ according to the practice (Barron, 1993). While this situation may cause deficient approaches in the aim of obtaining certain values, it has been a guiding light in terms of acoustic quality. Objective parameters can be associated with subjective parameters (Gade,2007).

For this study, the objective parameters that were investigated are: reverberation time (RT), early decay time (EDT), clarity (C_{80}), definition (D_{50}), early lateral energy fraction (LF_{80}), late arriving lateral energy (LG_{80}) bass ratio (BR) and treble ratio (TR).

2.2.1.1. Reverberation Time

When a sound source in a closed space is active, direct sound followed by early reflections and late reflections occupy and fill the space. As the reflected sounds and absorbed sounds are evened out by each other, a state of equilibrium is reached. From this moment on, no changes are observed in the sound level as long as the source is kept active. When the source is turned off, the sound level in the space begins to fade gradually. This process is called reverberation, and the time required for a sound to decrease by 60 dB after its active source has been switched off is called reverberation time (RT) (Mehta, 1999).

In some cases, the existing sound level in a space may not be high enough to observe a 60 dB decay, nevertheless; RT can still be determined since it is a unit of velocity. Generally, RT is identified for certain frequencies in octave bands such as 125, 250, 500, 1000, 2000 and 4000Hz (Beranek, 1996).

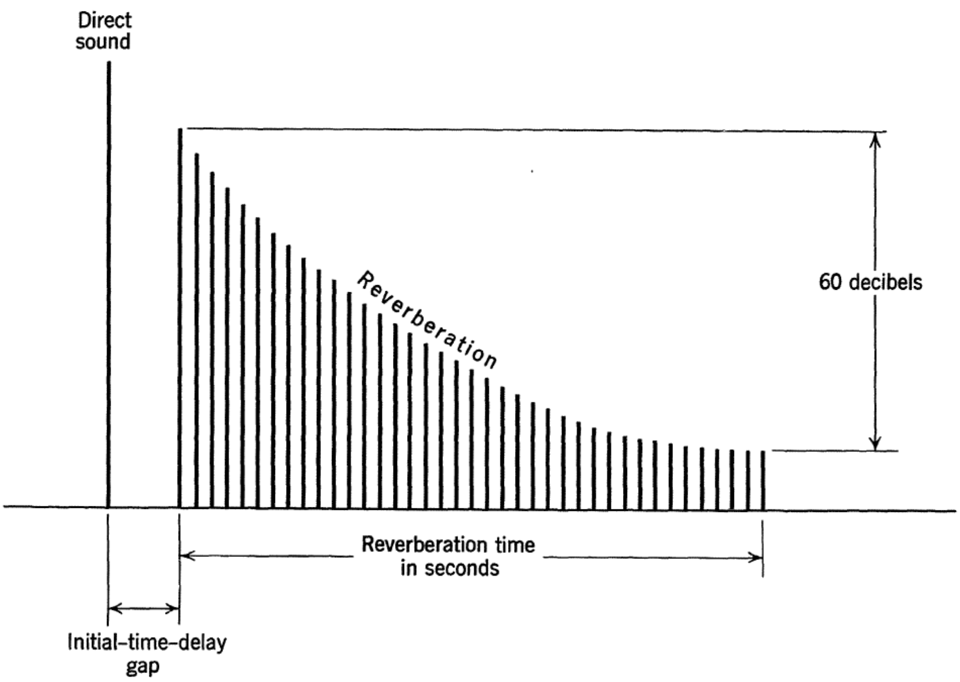


Figure 2.1. Demonstration of reverberation time (Beranek, 2004)

Earlier research relating to reverberation time has been done in the beginning of the 20th century by Walter C. Sabine who used to carry on with his studies as a physics professor in Harvard University. After a request regarding on solving the acoustic problems that were causing difficulties of intelligibility in the New Fogg Art Museum auditorium, Sabine had started experiments in three of Harvard's auditoriums. Eventually, Sabine had come up with a theory about sound absorption qualities of materials and had explained a relationship with material absorption and sound decay, thus coming up with an equation for RT (Long, 2006). The outcomes of his studies pointed out that in theory, RT is equal in the entirety of a space, independent of the position of the sound source. The effect of an absorbent surface is also in theory independent of its position in the space. By this means, the RT equation was developed to only depend on the volume and total absorption (Beranek, 1996).

$$\boldsymbol{RT_{60} = 0.161 \cdot V / A} \qquad [2.1.]$$

RT_{60} = reverberation time in seconds

V = room volume in m^3

$A = \boldsymbol{\alpha} \cdot \boldsymbol{S}$ = equivalent absorption surface or area in m^2

α = absorption coefficient

S = absorbing surface area in m^2

$A = \alpha_1 \cdot S_1 + \alpha_2 \cdot S_2 + \alpha_3 \cdot S_3 + ..$

Sabine's equation for RT is shown above. With this equation, the total absorption of a space can be determined by multiplying surface areas by their relative absorption coefficients and then adding the results together. By dividing the volume to this value, the RT of a space can be determined. As can be figured out from the equation, RT values differ according to the size and function of a space. An example of different RT values for different sized spaces used for various purposes can be seen below in Figure 2.2. (Maekawa, 1994).

In spaces that are designed for speech, the reverberation time is required to be as low as possible for the intelligibility of speech, in other words; acoustically "dead" spaces are preferred for speech purposes (Long, 2006). On the contrary, reverberation is a beneficial quality for concert halls and opera houses where a musical impression needs to be created. Reverberating sound provides fullness in the tone by filling the gaps in between notes. Therefore, composers beginning from the 16th century have used large cathedrals with high RT for choral and religious music (Beranek, 2004).

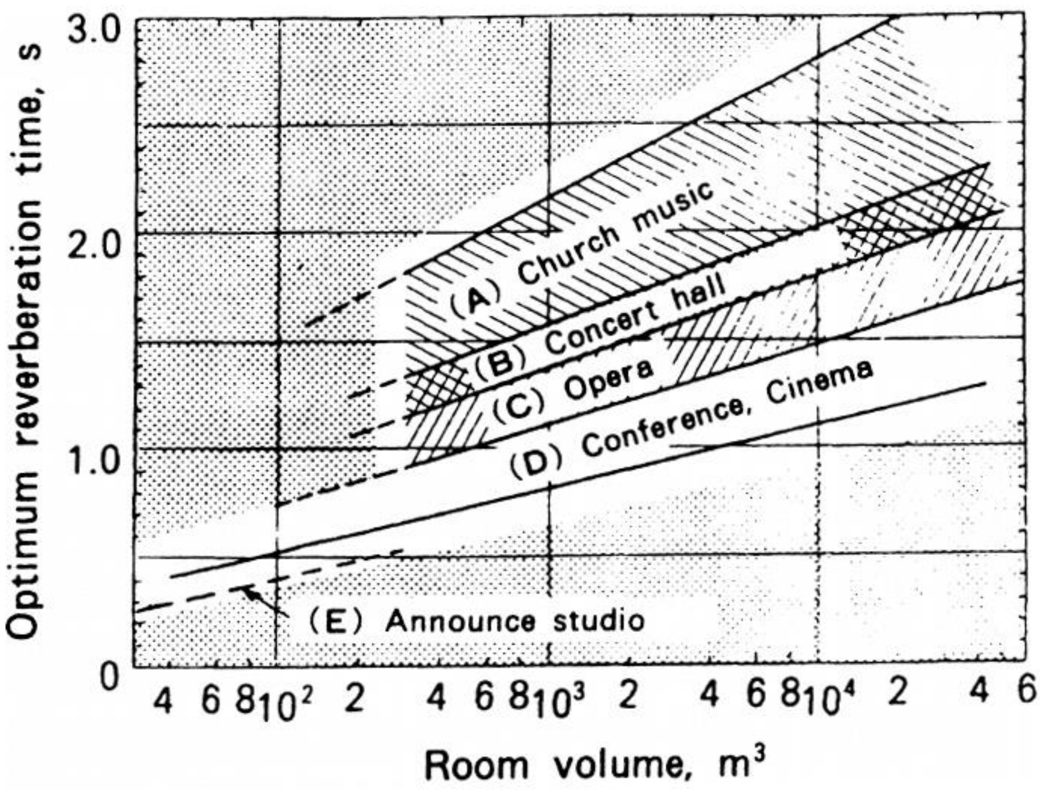


Figure 2.2. Optimum reverberation times at 500 Hz for different types of spaces (Maekawa, 1994)

RT values in addition to the graph above can be generally accepted as between 1,8 – 2,2 seconds for music spaces, between 1,3 – 1,8 seconds for opera houses and between 0,7 – 1,0 seconds for spaces for speech, in 500Hz (Barron, 1993).

2.2.1.2. Early Decay Time

Earlier studies by Sabine and other researchers regarding reverberation time, have suggested that the decay of the sound level after the source has been shut down followed a constant decrease within the 60 dB decay process. However, applied experiments in real concert halls have unveiled that this process might not be homogenous. Since in speech and music, the subsequent later section of a reverberation may be masked due to the upcoming sounds or notes, thus the sound decay process can only be perceived within breaks. This situation has brought upon an alternative parameter to RT, which is early decay time (EDT) that has yielded better correlations with reverberation during ongoing music or speech (Gade, 2007).

Early decay time examines the initial decay part of the sound and allows a comparison with RT. To be put on technical terms, EDT is defined by multiplying the time it takes for sound to decrease from 0 dB to -10 dB with 6. The reason for multiplying the duration with 6 is to provide a correlation with RT in order to make easier comparisons. This way, differences between the earlier decreases in sound levels and the reverberation times can be distinguished (Beranek, 1996).

In rooms where uniform sound distribution is observed, the RT and EDT values are considerably close to each other, even equal in some cases. The sound decay process is uniform and linear in these situations (Barron, 1993). However, in cases where the sound distribution is uneven, sound decay diagrams show refractions despite RT values being the same (Mehta et al, 1999).

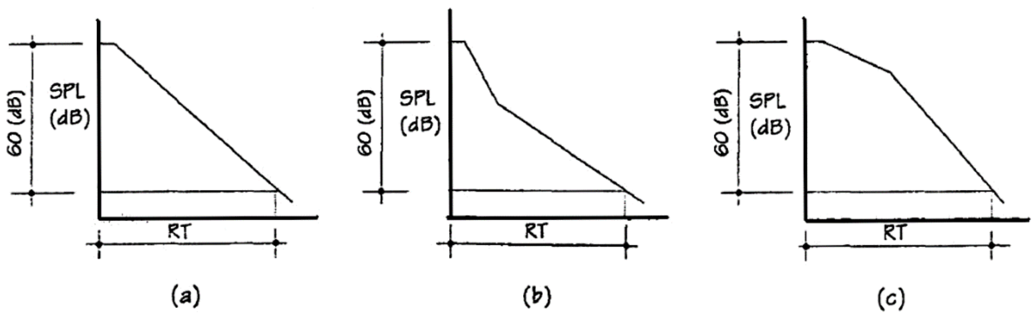


Figure 2.3. Graphs of different sound decays of rooms with equal RT values (Mehta et al, 1999)

Different sound decay diagrams of spaces with equal RT values by Mehta et al (1999) are shown in Figure 2.3. Diagram (a) belongs to a space where uniform sound distribution can be observed in such manner the EDT and RT values are equal, making the decay in early and late reflections linear. On the other hand, diagram (b) shows that the EDT and RT values are different from each other. In this case, early reflections decay faster than late reflections, which can be interpreted as the EDT being shorter than RT. The shorter EDT allows to prevent masking and shows an increase in intelligibility and clarity. Lastly, diagram (c) shows a case where the EDT value is higher than RT. This causes the sound to lose its intelligibility, but also makes the musical feeling of envelopment to increase (Mehta et al, 1999). It was found out that cases where EDT values are 1.1 times bigger than RT values yield the best acoustic conditions in concert halls and opera houses (Beranek, 2004).

Even though EDT may be used to better express reverberance as opposed to RT, the essential parameter is still considered as RT. The reason behind this is the fact that most of the room acoustic parameters affiliate with RT and RT is also referred to in regulations concerning room acoustics in structures (Gade, 2007).

2.2.1.3. Clarity

Being an important parameter for music, clarity (C_{80}) is measured by dividing the direct sound energy to the sound energy that is produced 80 milliseconds after the initial sound. This parameter is also referred to as early-to-late sound index. Clarity was first derived from the distinctness (D_{50}) parameter that was found by Thiele in 1953. The distinctness parameter used 50 milliseconds as a time gap for speech intelligibility, which was then changed to 80 milliseconds to be used for music by the proposal of Reichardt in 1975, becoming what is used today as C_{80} (Barron, 1993).

As seen in the equation below, C_{80} is basically the ratio of early sound energy and late sound energy. This equation was afterwards transformed to be used with speech, by decreasing the time limit from 80 milliseconds to 50 milliseconds, creating the C_{50} parameter, which is directly linked to the D_{50} parameter (Beranek, 2004).

$$C_{80} = 10\log\ (\text{early sound energy} / \text{late sound energy}) \qquad [2.2]$$

The clarity parameter is affected by the tempo of music, decreasing as the tempo increases. This is caused by the increase of late sound energy (Barron, 1993). Therefore, clarity is inversely proportional to the sound fullness in a room. Since fullness is dependent on RT, C_{80} is inversely proportional to RT as well (Mehta, 1999). Beranek (1996) has proposed that optimum C_{80} values vary between -4 dB and +4 dB while Barron (2009) stated that optimum values may vary between -2 dB and +2 dB.

2.2.1.4. Early Lateral Energy Fraction and Late Arriving Lateral Energy

The early lateral energy fraction (LF_{80}) parameter was first derived from subjective tests where spatial impression (SI) was measured by a linear system. This parameter is calculated by dividing the sound pressure level (SPL) of early lateral sounds to the SPL of early omnidirectional sounds in the first 80 milliseconds coming after the direct sound. Further studies have found out that LF_{80} can be correlated with the apparent source width (ASW) which is a subjective parameter (Barron, 1993). The optimum LF_{80} values that were proposed are between 0,15 – 0,20 for chamber music (Gade, 2007) and 0,10 – 0,35 for classical music (Long, 2006).

Studies done by Bradley and Soulodre (1995) have showed that late arriving lateral energy (LG_{80}) is directly connected to the subjective acoustic parameter Listener Envelopment (LEV). It was found out that LEV could solely be observed under situations where LG_{80} is present. It was also found out that listeners' ability to distinguish the effects of early lateral reflections would decrease in the presence of late arriving lateral energy (Bradley & Soulodre, 1995).

2.2.1.5. Bass Ratio and Treble Ratio

Bass ratio (BR) is the ratio of the RT in low frequencies to the RT of mid frequencies. It can be calculated by dividing the sum of RT in 125Hz and 250Hz to the sum of RT 500Hz and 1000Hz. Treble ratio is the ratio between the sum of RT in 2000Hz and 4000Hz and the sum of 500Hz and 1000Hz (Everest & Pohlamann, 2009). Bass ratio is used to determine the subjective parameter "warmth" in rooms. The equation for bass ratio is presented below (Barron, 1993).

$$BR = (T_{125Hz} + T_{250Hz}) / (T_{500Hz} + T_{1000Hz}) \quad [2.3]$$

In spaces with RT values of 1.8 seconds and higher, the recommended BR value varies between 1.1 and 1.25. For spaces with RT lower than 1.8 seconds, BR values between 1.1 and 1.45 is recommended. Rooms with BR values lower than 1.0 lack of warmth. On the other hand, BR values that are too high should be avoided (Mehta et al, 1999).

2.2.2. Subjective Acoustic Parameters

Subjective parameters cannot be measured or calculated, unlike objective parameters. Physically measurable values may give predictable results in room acoustics, however; it is not an easy task to make assumptions based solely on measured values. While one listener in a room might consider the acoustic quality sufficient, another may think of it as inadequate, thus pointing out different acoustic characteristics in a room. Therefore, subjective parameters should be taken into consideration just as much as objective parameters when it comes to acoustic design (Barron, 1993).

For this study, the following subjective parameters are used: definition and clarity, reverberance, warmth, intimacy, listener envelopment and balance.

2.2.2.1. Definition and Clarity

Musically speaking, definition and clarity are terms with similar meaning. Both describe the circumstance where the sounds during a musical performance could be distinguishable from each other. There are two types of clarity: horizontal clarity and vertical clarity (Beranek, 2004).

Horizontal clarity can be explained as the distinguishability of subsequent sounds. The performer or composer can determine the musical qualities that affect clarity such as tempo, repetition of notes and relevant loudness of successive notes in their own preference. Objective acoustic parameters that affect clarity are reverberation time (RT) and early decay time (EDT) (Beranek, 1996).

Vertical clarity, on the other hand, is a parameter that defines the ability to tell apart simultaneously played sounds, which relies on the performer/composer, room acoustic quality and the hearing level of the listener. The composer may define vertical clarity by choosing the notes that would be played together, the notes surrounding them and the instruments these notes would be played on. Vertical clarity determines the harmony between different instruments and early decay time, as well (Beranek, 1996).

2.2.2.2. Reverberance

In a room, as mentioned earlier in objective acoustic parameters, after the initial direct sound and the following reflections occur, the total sound energy in the room start to remain constant. Later, when the sound source is shut down, the reflected sounds begin to decay gradually. This process is called reverberation (Türk, 2011).

Reverberance is the subjective equivalent of RT and is particularly related to indoor sounds. When a note is played, for instance, the listener first hears the direct sound coming from its source, and the reflected sounds afterwards. The value of reverberance is directly dependent on RT (Beranek, 2004).

2.2.2.3. Warmth

Musical warmth is defined as the liveness of bass or the fullness of the bass tone relative to the mid frequency tone. The warmth of the bass tone can be achieved if the RT of low frequencies between 125 – 250Hz are longer than the RT of mid frequencies between 500 – 1000Hz. On the contrary, if this ratio between low and mid frequencies is too high, irregularities between sounds may occur and may cause what can be called “humming” sounds. The subjective warmth parameter is directly linked to the objective bass ratio parameter (Beranek, 1996).

2.2.2.4. Intimacy

The visual intimacy in a room depends on how the users perceive the surroundings of the room as they were close. The same case applies to sound, meaning it is perceived as it was coming from a nearby surface, which is called acoustic intimacy. If music played in a small room also sounds as if it is being played in a small room, thereby the said room has acoustic intimacy. The indicator of a listener’s impression on the size of a room is the time between the direct sound and the first reflection which is the initial time delay gap parameter (ITDG) (Beranek, 2004).

While Beranek (2004) correlates intimacy with ITDG, it was later found out that intimacy also relies on the room volume. Smaller volumes yield shorter ITDG values, thus the intimacy feeling is stronger in smaller rooms. Shorter values of ITDG also point out to shorter EDT values. Therefore, as EDT values decrease, intimacy is increased (Long, 2006).

2.2.2.5. Listener Envelopment

Listener envelopment (LEV) can be described as the listener’s feeling of being surrounded by sound and music around them. Research has found out that LEV could be linked to RT, EDT, C_{80}, LF_{80} and LG_{80} individually. Each parameter has a different level of effect on LEV. While RT, EDT and C_{80} have significantly less effect on the assessment of LEV, LF_{80} and LG_{80} were discovered to be highly correlated with it. Studies have shown that there is a 97% consistency between LEV and LF_{80}, while LEV and LG_{80} have a consistency of 99,7% in between. Therefore, the LG_{80} parameter is considered to be the most reliable for measuring LEV (Bradley & Soulodre, 1995).

2.2.2.6. Balance

A well balanced acoustic space requires for the orchestral sections and the solo musicians to be in harmony with each other. Balance might be lost from time to time in a performance, which may be caused by the stage being on center, being too close the musician during certain parts of a performance, or a solo performance not being supported sufficiently. Alongside, balance depends on the musicians and their seating on the stage, and the authority of the conductor. Furthermore, the balance in an opera house between the orchestra and the singers relies on stage design, support of early reflections to the singer and the design of the orchestra pit (Beranek, 2004).

2.3. Specifications of Performance Spaces

This section talks about essential information that is needed when designing spaces where listening is the key function, such as physical conditions of a room and the required acoustic parameter values. Afterwards, acoustic evaluation examples from different studies and researchers are presented.

2.3.1. Acoustic Design Criteria

Architectural acoustic design has developer over the years all the way from ancient Greek theaters to multi-purpose halls of the 20th century. Recent studies have made it possible to achieve a better understanding between overall acoustic quality and the geometrical characteristics of a room. Design parameters such as form and size affect objective acoustic parameters, hence having an impact to determine subjective influence in performance spaces (Kwon & Siebein, 2007).

Rooms with different functions require different needs in terms of design. In rooms for speech, the main goal is for the listener to understand the speaker, in other words, clarity, along with preserving the ability to locate the position of the sound source which is most essential for theaters. Rooms for music, on the other hand, have five different parameters for optimum values to be provided (Hawkes & Douglas, 1970). These five parameters are as follows:

- Room size
- Room shape
- Purpose of use
- Stage proportions
- Design of the audience area

2.3.1.1. Room Size and Shape

The initial subject of matter in acoustic design is the size of the space. The sizes of performance spaces should be determined based on their function and number of listeners. The optimum volumes of rooms with different functions would be different from each other (Barron, 1993).

Table 2.1. *Volume ratios depending on function*

Function	***Volume per person (m3)***
Speech	2,5 – 4
Theater	4 – 6
Opera	6 – 8
Multi-purpose	6 – 8
Music	8 – 11

As air itself has an absorbent tendency for frequencies of 1000Hz and higher, room size affects total absorption and RT values. Studies have shown that the required volume per person varies depending on the function (Kuttruff, 1991). Examples showing optimum volumes per person is presented above in Table 2.1.

Alongside size and volume, the shape of a room is considered one of the most important criteria for acoustic design, as well. Performance halls that were designed up until today share a common problem to solve; the sound coming from its source to reach all listeners as equally as possible, and for it to provide the needs of the function. For instance, rectangular (or shoebox) shaped halls are preferred for concert halls whereas horseshoe shaped plans are commonly used for opera (Haan, 1993).

Traditionally, plan types can be categorized in four groups (Barron, 1993):

- Rectangular
- Fan
- Horseshoe
- Geometrical

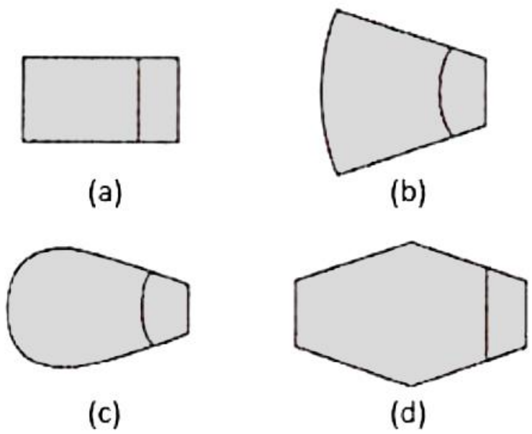


Figure 2.4. Plan types for performance spaces:
a) rectangular type b) fan type c) horseshoe type d) geometrical type

The rectangular or horseshoe plan type has been considered the most trustable design method for performance halls, along with its convenience of construction, as long as appropriate sizes are chosen. The parallel lateral walls provide adequate early and late reflections thus increasing spatial impression (Long, 2006). However, as the size and the number of listeners increases, the width and depth of the room increases as well, causing a decay in the sound level through the back areas of the space (Egan, 2007).

Fan type halls are usually preferred as the room size increases. The biggest benefit gained from fan type halls is the ability to place more listeners closer to the stage by enlarging the sides. This however, brings a disadvantage along. Since the rear wall is concave shaped, an acoustic problem called focusing might occur. This may be solved by placing scattering materials on the rear wall, or changing the center of focus on the rear wall by manipulating the radius of the concave (Everest & Pohlamann, 2009).

Horseshoe plan types are used mostly for opera houses, rather than concert halls. Listeners are seated along the walls to provide further absorption and sound can reach all listeners homogenously, as well. These types of halls might also suffer from a problem of focusing (Beranek, 2004).

Geometrical plans today are designed by incorporating together different aspects of the traditional plan types, such as using parallel lateral walls with a concave rear wall or rooms with complex geometries that have walls that are placed in different angles to form uneven shapes (Kwon & Siebein, 2007).

Despite the fact that ideal forms and shapes are present for each function and design, there are some common design criteria that all of the aforementioned plan types suggest. Rooms with too large depth or rooms that are too wide with little depth should be avoided. Places that are close to the stage should be more reflective as well as lateral walls, while rear walls should have absorbent materials. Parallel surfaces should be covered with scattering material in order to prevent lateral echoes and finally, low ceilings should be avoided (Mehta et al, 1999).

2.3.1.2. Purpose of Use

There are a number of purposes of use that are needed in a performance space. While a space may be designed in the aim of serving a single purpose, having a flexible design that allows the space to be used for multiple purposes might also be the case. The first step is to determine the initial purpose of a performance hall (Barron, 1993).

For concerts, the situation might change depending on the type of orchestra, such as a symphony orchestra that includes an average of 90 people or chamber orchestras which include 10 – 12 musicians up to 40 – 50 in some cases. Recitals on the other hand, are the smallest scaled musical performance which consist of solo singers and virtuosos (Kuttruff, 2006).

Theatre or drama generally includes more than 12 performers; however, it might vary between 2 to 20 people depending on the play. Operas, ballets and musicals occasionally consist of singers, dancers, choirs and an orchestra. They require specific stage design alongside an orchestra pit and storages/warehouses for décor. The stage is usually divided with a curtain (Egan, 2007).

2.3.1.3. Stage Proportions

Stage form and size is an important subject in terms of creating suitable acoustic conditions for the musicians and affecting how these conditions are perceived by the audience. It is essential for the musicians to hear each other effectively and receiving positive feedback from the audience. A stage shell that envelops the orchestra is considered to be effective on the subjective and objective evaluations of the room and the acoustic performance of the musicians (Gade, 1989).

The stage walls and ceiling is also an essential part of the process of reflecting sounds to the audience. Additionally, if the stage is designed too wide, listeners on the sides of the stage might hear instruments that are closer to them before the ones that are not. On the contrary, if the stage is too deep, sounds of the instruments from the back line of the orchestra might reach the audience with a time delay (Mehta et al, 1999). In order to avoid these circumstances, it is acceptable to design a stage that assures optimum conditions, instead of a sizable stage. For symphony orchestras, a stage platform that is 16,7 meters to 12,2 meters is generally recommended. An area of 150 meter squares is adequate for an orchestra of 100 people. Moreover, the ceiling of the stage should not be any higher than 6 – 8 meters (Beranek, 2004). Ultimately, the stage floor should be elevated from the audience area in order to accommodate both visual and acoustic comfort. However, this elevation may not be higher than 1,05 meters, since it would break line of sight for the initial rows of the audience (Barron, 1993).

2.3.1.4. Design of the Audience Area

An average person begins to lose line of sight starting with facial expressions at 12 meters, gestures at 20 meters and body movements at 30 meters. For this reason, the audience area needs to be limited to a maximum of 40 meters from the stage in order to maintain both acoustic and visual comfort (Haan, 1993).

The absorption coefficient of the listeners is directly linked to the total absorption of a room, which also affects reverberation time. Therefore, the audience area is a significant factor for acoustic design. It is recommended that the audience area should cover a space as small as possible. However, if large numbers of listeners are to be seated, a suggested solution might be designing a balcony (Barron, 1993).

In performance spaces where a balcony is present, the ceiling and the bottom surface of the balcony should be designed to allow reflected sounds to reach the listeners in the back. As shown in Figure 2.5., if the balcony is too deep or if its height is too low, reflected sounds may not reach the audience, creating an acoustic shadow. Hence, balconies should be designed by keeping this situation in mind (Beranek, 1996).

The absorption coefficient of the seats is also a matter of importance and should be as near as possible to the absorption of the listeners, eliminating the possibility of changing the room's total absorption in case there are few listeners present. The placement of the seats should be so that the listeners do not have any trouble seeing the stage. This should be done by making the seating area inclined as the rows go further and shifting the seats for each row in order to prevent the listeners from breaking the line of sight from the back rows (Kwon & Siebein, 2007).

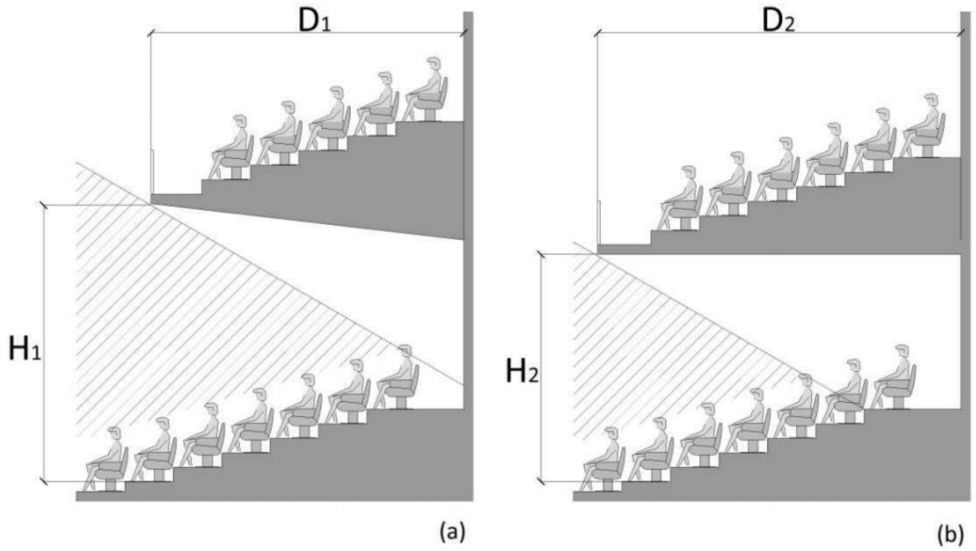


Figure 2.5. Examples of balcony design;
a) Bigger height with a smaller depth b) Smaller height with a bigger depth

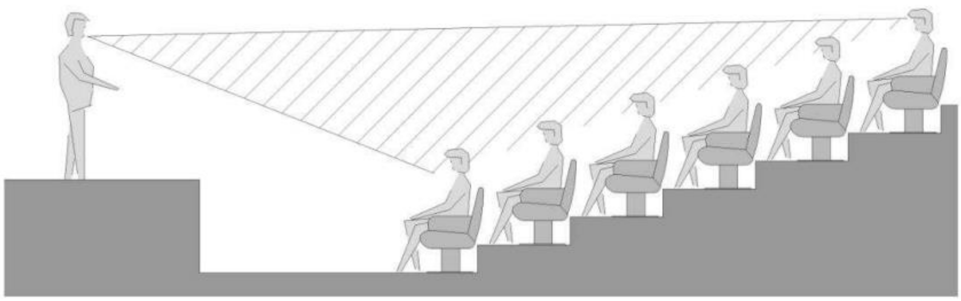


Figure 2.6. Example of audience seating position

2.3.2. Acoustic Evaluation of Performance Spaces

There are many systems for the acoustic evaluation of performance spaces, which vary from one acoustician to another. This is mainly due to the importance of a certain acoustic parameter for a certain acoustician. Therefore, every acoustician has their own evaluation system. Some examples that are globally acknowledged are presented in this section of this thesis.

Leo Beranek has evaluated 72 concert halls and opera houses in his book he wrote in 1962. In this evaluation system, Beranek has given each parameter a point. By adding up these points, he has compared performance spaces based on their total points. Beranek's evaluation system is shown below in Table 2.2. (Maekawa, 1994).

Table 2.2. *Leo Beranek's evaluation system (1962)*

Parameter	**Physical quantity**	**Rating points**	**Max. point**
Intimacy	Initial time delay gap (ms)	0-20 ms: 40 pts. >70 ms: 0 pts.	40
Liveness	Reverberation time (s) at mid frequencies (500-1000Hz)	Longer or shorter time than optimum gives lower points	15
Warmth	Average RT at 125 and 250Hz divided by RT at 500-1000Hz	RT larger or smaller than 1,2-1,25 gives lower points	15
Loudness of direct sound	Distance between listeners and the sound source	18 meters (1 point reduction for each extra 3 meters)	10
Loudness of reverberant sound	$(RT / V) \times 10^6$	3.0 (larger or smaller gives lower points)	6
Diffusion	Irregularities on the walls and ceilings	If satisfactory	4
Balance and blend	Balance between sections of the orchestra	If satisfying	6
Ensemble	The orchestra's capability to hear each other	If convenient	4

Beranek has later on gone for some changes in the evaluation order he had made in his system, creating a new system, which is shown in Table 2.3. (Long, 2006).

Table 2.3. *Leo Beranek's evaluation system (1996)*

Parameter	**Physical quantity**	**Max. point**
Apparent Source Width	$IACC_{E3}$	25
Early Decay Time	EDT	25
Surface Diffusivity Index	SDI	15
Loudness	G_{mid}	15
Initial Time Delay Gap	ITDG	10
Bass Ratio	BR	10

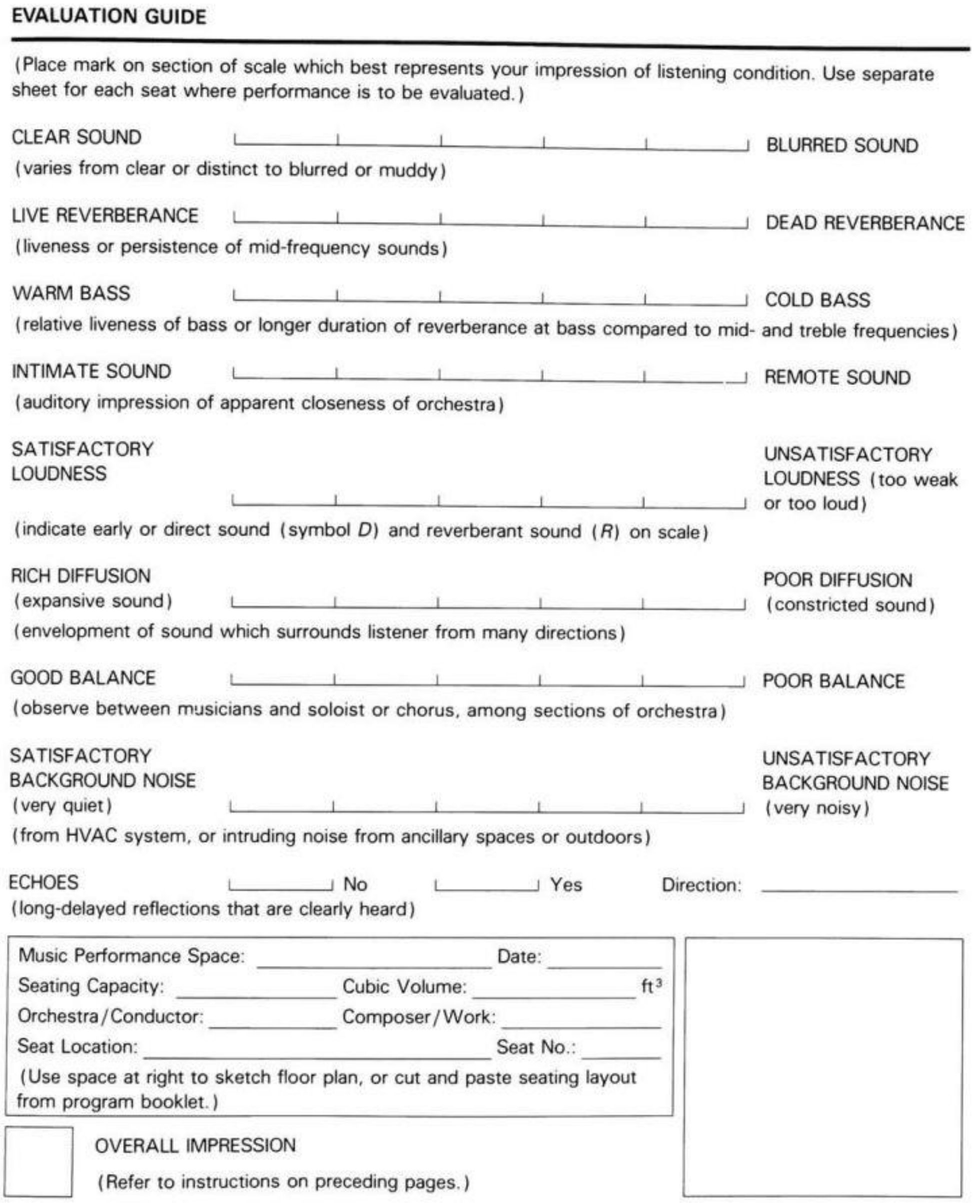
In his study regarding concert hall acoustics, Yoichi Ando (1985) have focused on evaluating the parameters based on percentage. Ando has made his system in accordance to his work, presented in Table 2.4. below (Maekawa, 1994).

Table 2.4. *Yoichi Ando's evaluation system*

Parameter	**Percentage**
(1-IACC)	25%
EDT	25%
SDI	15%
G_{mid}	15%
t_1	10%
BR	10%

Michael Barron, in addition, has also informed readers in his study regarding theatres in the book he wrote in 1993. Barron has taken into consideration the following parameters in the evaluation of theatres: reverberation time, early energy fraction, sound pressure level and background noise level (Barron, 1993).

M. David Egan (2007) has created an evaluation system for both acousticians and the listeners or performers to report their subjective impressions about performance spaces for music. The main goal is to allow users to familiarize with the acoustic properties of a space. Users grade each parameter by giving them points based on their impression, following by giving the performance space an overall rank. An empty and a filled example of the evaluation system is given in Figure 2.5. and 2.6. (Egan, 2007).



EVALUATION GUIDE

(Place mark on section of scale which best represents your impression of listening condition. Use separate sheet for each seat where performance is to be evaluated.)

CLEAR SOUND — BLURRED SOUND
(varies from clear or distinct to blurred or muddy)

LIVE REVERBERANCE — DEAD REVERBERANCE
(liveness or persistence of mid-frequency sounds)

WARM BASS — COLD BASS
(relative liveness of bass or longer duration of reverberance at bass compared to mid- and treble frequencies)

INTIMATE SOUND — REMOTE SOUND
(auditory impression of apparent closeness of orchestra)

SATISFACTORY LOUDNESS — UNSATISFACTORY LOUDNESS (too weak or too loud)
(indicate early or direct sound (symbol *D*) and reverberant sound (*R*) on scale)

RICH DIFFUSION (expansive sound) — POOR DIFFUSION (constricted sound)
(envelopment of sound which surrounds listener from many directions)

GOOD BALANCE — POOR BALANCE
(observe between musicians and soloist or chorus, among sections of orchestra)

SATISFACTORY BACKGROUND NOISE (very quiet) — UNSATISFACTORY BACKGROUND NOISE (very noisy)
(from HVAC system, or intruding noise from ancillary spaces or outdoors)

ECHOES ____ No ____ Yes Direction: ____
(long-delayed reflections that are clearly heard)

Music Performance Space: ____ Date: ____
Seating Capacity: ____ Cubic Volume: ____ ft^3
Orchestra/Conductor: ____ Composer/Work: ____
Seat Location: ____ Seat No.: ____
(Use space at right to sketch floor plan, or cut and paste seating layout from program booklet.)

OVERALL IMPRESSION
(Refer to instructions on preceding pages.)

Figure 2.5. M. David Egan's evaluation system (empty)

EVALUATION GUIDE (EXAMPLE APPLICATION)

(Place mark on section of scale which best represents your impression of listening condition. Use separate sheet for each seat where performance is to be evaluated.)

CLEAR SOUND ✓ BLURRED SOUND
(varies from clear or distinct to blurred or muddy)

LIVE REVERBERANCE ✓ DEAD REVERBERANCE
(liveness or persistence of mid-frequency sounds)

WARM BASS ✓ COLD BASS
(relative liveness of bass or longer duration of reverberance at bass compared to mid- and treble frequencies)

INTIMATE SOUND ✓ REMOTE SOUND
(auditory impression of apparent closeness of orchestra)

SATISFACTORY LOUDNESS R D UNSATISFACTORY LOUDNESS (too weak or too loud)
(indicate early or direct sound (symbol *D*) and reverberant sound (*R*) on scale)

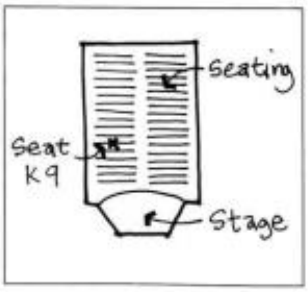
RICH DIFFUSION (expansive sound) ✓ POOR DIFFUSION (constricted sound)
(envelopment of sound which surrounds listener from many directions)

GOOD BALANCE ✓ POOR BALANCE
(observe between musicians and soloist or chorus, among sections of orchestra)

SATISFACTORY BACKGROUND NOISE (very quiet) ✓ UNSATISFACTORY BACKGROUND NOISE (very noisy)
(from HVAC system, or intruding noise from ancillary spaces or outdoors)

ECHOES ✓ No ___ Yes Direction: ______
(long-delayed reflections that are clearly heard)

Music Performance Space: Gallifrey Music Hall Date: 13 Feb 95
Seating Capacity: 2,000 Cubic Volume: 625,000 ft³
Orchestra/Conductor: Dr. Whom Composer/Work: Shostakovich Symphony No. 10
Seat Location: Main level near side wall Seat No.: K9
(Use space at right to sketch floor plan, or cut and paste seating layout from program booklet.)



B+ OVERALL IMPRESSION
(Refer to instructions on preceding pages.)

Figure 2.6. M. David Egan's evaluation system (filled)

2.4. Brief Information on Turkish Classical Music

In this section, Turkish classical music (TCM) is examined, starting with the chronological timeline of TCM beginning from the origins of Turkish music followed by the Ottoman period and up to this day. Afterwards, the characteristics of TCM is inspected in terms of musical aspects and instruments. Finally, some examples are given from the places that TCM was performed during the Ottoman period.

2.4.1. History of Turkish Classical Music

The history of Turks is known to descend as far as the Altais. (Özgür & Aydoğan, 2015). Since the ancient times, the Turks have scattered over a wide area on Asia, creating their own cultural values as well as integrations with different cultures such as Chinese, Persian, Indian, Arabic and Bizantian, creating the stepping stones of the values of today (Yener, 2014). The evolution, transformation and development of music throughout history can be commonly linked to the social structure of a commune (Körükçü, 1998). History of music can also be defined as humanity's way of expressing their ways of living and epochal emotions and ideas through the use of instruments and sounds (Özgür & Aydoğan, 2015). Thus, it can be considered essential that the Turkish communal structure has to be clarified in order to understand today's Turkish classical music (Körükçü, 1998).

Turkish music is without a doubt an influential aspect of Turkish culture, carrying the traces of a rich cultural heritage (Yener, 2014). Yener states that the Turkish history of music is not a scientific area that was researched comprehensively to this day. Some historians and musicologists assume that music in Turks has been a part since the origins of Turkish history, while others talk about a musical history of 6000 years in Turks. Since it was difficult to obtain written documents before the last 1500 years, of Turkish history, cultural and social data on the previous periods are quite limited (Körükçü, 1998).

When viewed in chronological order, it can be seen that the Turkish culture has reached today via five different periods which are Central Asia, Ancient Anatolia (Mediterranian and Aegean), Islam, the Ottoman era and finally western culture (Can & Levendoğlu, 2002). In the very beginning, like in other primitive societies, there have been individuals who have undertaken the roles of an enchanter, healer or bard in the Altai commune. These people were called shamans and the music they made was described as shamanic music. The shamans, having a strong impact on society, used to sing hymns and requiems on important days for the society (Uçan, 2000). Research shows that the Altai melodies which first started on two frets, reaching to four frets in time, were simple melodies despite the varieties in rhythm, and human voice stood out among the instruments (Özkan, 2013). The very first accompanying instruments were found to be the drum and def, furthermore it is considered that the horn (boru) and lute (kopuz) have taken their first forms in the Altai era.

The first written documents regarding central Asian music were believed to be gathered from Chinese sources. According to these sources, travelling Turkish musicians would stay at Chinese palaces for long periods and have gained reputation while doing so. The relationship with the Chinese has especially increased during the Hun Empire, thus creating mutual cultural interactions (Malm, 1967). According to Malm, musical movements originating from centers of commerce like Hotan, Kuça and Turfan have affected China significantly, making western Turkistan music influential in northern China. It is also known that during the Hun Empire period, according to old Turkish tradition, women and men would dine and play instruments together in holidays and celebrations (Özgür & Aydoğan, 2015). Another important tradition seen in central Asia beginning from the Hun period was the establishment of the brigadier (tuğ) party. This custom that uses the drums and banners as a symbol of power has stretched all the way up to the Ottoman era, resulting in the birth of the janissary band (mehter) tradition (Selanik, 1996).

Central Asia has been an important core for musical relationships throughout the Silk Road between the Near East and the Far East. Musical instruments and styles have been transported and have spread across settlements between caravan trails (Can, 2001). The Islamic period which started with the Arabic invasion in the closing of the 8th century has brought a new Near Eastern influence upon central Asia. Followinf this century, Islam has started to spread across the Turks (Lewis, 1968). From the first years of Islam, a new kind of music has started to arise with the mingling and blending of musical aspects of Arabic, Greek, Iranian and Turkish nations (Ugan, 1988). Turkish classical music has emerged as a product of urban culture and comprises of folk music, military music, religious music and classical music (Turabi, 1993). After moving from the nomadic lifestyle into sedentary living, urbanization has accelerated and writing has become literature. The effects of Arabic and Persian culture has also reflected upon language, making it possible to see these changes in the terminology of traditional TCM (Levendoğlu, 2005). Al-Farabi, the great physician and philosopher who lived in the 10th century has also had an interest in musical lore and had written "Kitab'ül Musiki el Kebir" (The Great Book of Music) in Persian, which is considered the most important literary piece about eastern music theory. Another important person in Turkish music, İbn-i Sina has also used Persian language when talking about music theory (Yener, 2014). After the translation of Greek musical pieces beginning from the 10th century, the physical and mathematical attributes of music have also started to be researched (Turabi, 2004). Turabi explains in his words that "Even though the thinkers of Islam have been influenced by Greek science and philosophy, they have enriched the present inheritance and thus have created and original musical literature".

The central Asian music culture which developed throughout the 8th and 13th century and have widespread across China, central Africa and the Caucasus, has reached its peak in the 14th century, only having to slowly lose its old value around the 15th century. Therefore, Islamic societies, mainly the Turks, Arabs and Persians have started establishing their own musical formations, each having their own personal characteristics (Can, 2001). It is considered that the starting period of what we accept TCM as of today has been built upon the time when the Ottomans became settled in palaces, which was towards the end of the 15th century (Körükçü, 1998). During this period, Hz. Mavlana and his mevlevi cult was an essential starting point for the development of Turkish music, followed by the southern Azerbaijani Turk Safiyuddin Urmevi who wrote two books about music in Arabic: "Kitabü'l Edvar" and "Risayetü'ş Şerefiye" (Yener, 2014). Another Azerbaijani Turk named Meragalı Abdulkadir has written six consequent books about Turkish music which are in the following order: "Cami'ul Elhan", "Makasid'ul Elhan", "Şerh'ul Kitab'ul Edvar", "Fervaid-i Aşere", "Zübbet'ül Edvar" and "Kenz'ül Elhan" (Körükçü, 1998). According to Körükçü, these six books are the foundations of future studies and are an influential source for knowledge about TCM in the past. In this period, Turkish music which had the traces of old traditions, has blended the values of Islamic culture into its fibre, creating the background of the style remembered as TCM today. Traditional formations that were brought from central Asia have formed into makams over time, becoming richer and richer.

During the 15th century, science and arts has progressed with the support from the palace and the sultans of the period. Musicians from across the globe have travelled to the Ottoman Empire, gathering in capitals such as İstanbul, Edirne and Bursa. The first examples of musical literature written in Turkish were found in this time period (Levendoğlu, 2005). The Enderun school of music that was established in Topkapı Palace was considered the biggest education center during the period where music was passed on via teacher-apprentice relationship (meşk) and where Turkish music was institutionalized and gained classical property (Körükçü, 1998). Another important establishment that used to give musical education were the Mevlevi lodges (Mevlevihane) where not only mevlevi music was taught, but non-religious and religious music, along with supporting practices such as literature and language were taught as well, followed by military lodges (Mehterhane) where the mehter tradition from the Hun Empire period was passed on (Ak, 2014). Music was also taught in dervish lodges (tekke), mosques and coffee houses which are briefly explained in the Section 2.3.3. of this chapter.

Following with the 16th century, the classical style has formed in Turkish music, growing apart from the Persian/Iranian influence to a more local style. Moreover, old musical patterns have changed along with the instruments, makams have been redefined, religious music has started to shape into unique forms and pieces were written in Ottomani Turkish instead of Arabic and Persian (Behar, 2015). The 17th century is considered as a critical point for Turkish music due to the fact that it had influenced the following centuries in terms of musical history (Gürbüz, 2010). During this period, musicians from abroad have come to Istanbul to both teach and learn about music where they were introduced to military “mehter” music which they further on were influenced by to form bands similar to mehter (Tanrıkorur, 2011).

After the 18th century had arrived, Turkish music has continued to thrive while composers kept sticking to the customs of classical style and adding some improvements to it, making the classical period reach its peak. Between the years 1718 and 1730, an era of tranquility and peace called the Lale (Tulip) Period had taken place, where relations with Europe have been increased, causing the start of a “westernization” time for the Ottoman Empire. These changes in trade, culture and arts have also influenced music, resulting in the birth of song form (Gürbüz, 2010).

In this century, some individuals have tried to create a note system to write music down, and even though the first attempts by Nayi Osman Dede and Abdülbaki Nasır Dede have not been acknowledged in the musical district, the Armenian church preacher and composer Hampartzum Limoncuyan has created a note system which is remembered as “The Hampartzum Note” and has been acknowledged and used to write down many Turkish classical pieces, preventing them to be forgotten in the future (Behar, 2014). Between the 17th century to the 19th century which is considered as the “Classical Era” similarities have been found between TCM and western classical music. While in western music, concertos and symphonies were being composed, pieces in big forms such as Kar, Beste and Semai have been produced in TCM. These musical pieces were supported by aristocrats and the palace, making music become an art of order (Aşıroğlu, 2009).

Traditional Ottoman/Turkish music has lived its so called "golden age" in the 19th century. With the changes of ideas and politics in Europe, the understanding in arts have changed as well. With the developing of the middle class, a new audience has emerged and more diverse repertoires have come into topic (Ak, 2014). With the democratic movements in the Ottoman Empire, arts have come down to the common folk and has become simple, unlike the Classical Era, lyricism has blossomed, melodic structures have overgone changes and the forms have become smaller (Körükçü, 1998). In this period, the people have become interested in western music and this case has influenced a new movement to be born in music called romanticism. After the janissary household which was the state's main military unit was shut down in 1826, a formation of a new modern army has led to a change in Turkish music with the closing of the military music schools "Mehterhane" and opening of "Müzika-yı Hümayun" in its place, which would soon lead to the perish of the Enderun school (Kaygusuz, 2014). As Kaygusuz puts it, with western music taking its place in the palace because of the Müzika-yı Hümayun, piano parts have started to be written in Turkish pieces and new types of performances such as marches, opera, operettas and waltz have started to form. The addition of the piano has then caused traditional instruments like the kanun and oud to slowly be abandoned over time.

As the 19th century began to end and the 20th century took its place, classical rules and styles have collectively started to come to an end (Körükçü, 1998). This sudden envy to European style has caused Turkish composers to be pushed aside and composers have slowly started to become distant from the palace, with the most important of them being İsmail Dede Efendi (Karamahmutoğlu, 2014). Composer İsmail Dede Efendi has tried to adapt to this modernization in music, writing pieces in waltz rhythm, however, it is believed that he was unpleasant with the situation and changes of the era (Özcan, 2014). In shorter words, the period starting with the 17th century and ending with the 20th, was an era of modernization and westernization. Although local music was not completely frowned upon, the state had shifted from favouring Turkish music over western music, leading to an identity crisis and the disappearance of original Turkish classical music (Kaygusuz, 2014). After the shutdown of the Enderun music school in 1908, Turkish music was all on its own with the state withdrawing its funding and support. In this environment, music was kept being taught by people who still like and appreciate Turkish music in meetings in residences. By these civilian formations which are considered the foundations of the musical unions today, the people's musical needs were fulfilled and it was made possible to raise students in the sense of a school (Körükçü, 1998).

A school of drama was founded in 1912 named "Darü'l Bedai" which also had a musical branch in the aim of producing music for the plays. This was the first institution after the Enderun for Turkish music. Because of the difficult conditions of World War I, the Darü'l Bedai was forced to shut down, leading to the establishment of "Darü'l Elhan" (house of melody) which only taught music and worked to identify classical pieces (Paçacı, 1999).

After the declaration of the Republic in 1923, efforts were made to create a national identity and redefining the historical and cultural structure. These efforts have led the state to determine a western music-based policy, resulting in the dispatch of Turkish music from the Darü'l Elhan completely and having the school's name changed into the Conservatory (Körükçü, 1998). The first radio broadcast has aired in Turkey in 1927. With a movement started by Ziya Gökalp, who was neither a musician or a musicologist, Turkish music was completely banned from the radio in 1934 (Paçacı, 1999). According to Körükçü (1998), Ziya Gökalp had thought that a new form of music needed to be created by blending together Turkish folk music and western music and TCM to be completely banished. However, he had not been able to comprehend that TCM and folk music were the same in basis, just different in style and form.

Positive efforts in music have also been made in the Republican period despite the various complications and setbacks. The Ankara State Conservatory has opened in 1936 along with the Ankara Radio in 1938. The conservatory started the education of Turkish music once more when Hüseyin Saadettin Arel was made in charge of it in

1943 (Paçacı, 1999). Alongside these institutions, various other establishments were founded with the state's resources during the first 50 years of the Republic such as the Ankara State Opera and Ballet, the Presidential Symphony Orchestra, the Istanbul State Opera and Ballet and the İzmir State Conservatory (Kaygusuz, 2014). Another important progress was the establishment of the "State Conservatory of Turkish Music" in 1976, followed by the establishment of the "Ministry of Culture State Choir of Turkish Classical Music" in 1980.

With the growth of the record industry, many musicians have started to compose songs that are more easily understood and sang. Composers such as Muhlis Sabahattin and Sadettin Kaynak have written music in a form that was never seen before, influenced by western music. Another influential musician who had brought the tradition of solo singing to TCM was Nurettin Selçuk, who used to sing standing up and in a formal suit (Körükçü, 1998). This solo singing concept has withered in time, making concerts for the entertainment industry to surface, thus TCM performers have started to lose their old styles and attitudes. The Turkish Radio and Television (TRT) had been the protector of TCM up to the 1980s, yet; as private radios and networks have started broadcasting in the 1990s, the overall cultural and artistic understanding of Turkey had started to change. Today, with the growth of technology and the presence of the internet, various types of music are within reach and the musical preferences of the society has changed due to this case, thus popular music is more in demand and TCM is less likely to be preferred in an overall scenario.

2.4.2. Characteristics of Turkish Classical Music

The most important aspect that distinguishes Turkish music from western music is that Turkish music is monophonic whereas western music is polyphonic. In western music, an octave band consists of 12 sounds each with an equal interval in between. Turkish music, on the other hand, has 24 sounds with uneven intervals in an octave band. These sounds are called tones (perde) and in order to produce these sounds, different types of accidental signs are used in addition to the ones in western type music (Bingöl, 1999). In some makam forms, sounds between notes are divided into 9 equal intervals, with an exception of the E – F and B – C having 4 and a half intervals between. This creates a total of 54 microtones or “koma”s (Aydoğan & Özgür, 2015). These microtones have later on become more recognized and were generally used in songs, leaving the TCM with a total of 54 tones (Songar, 1988).

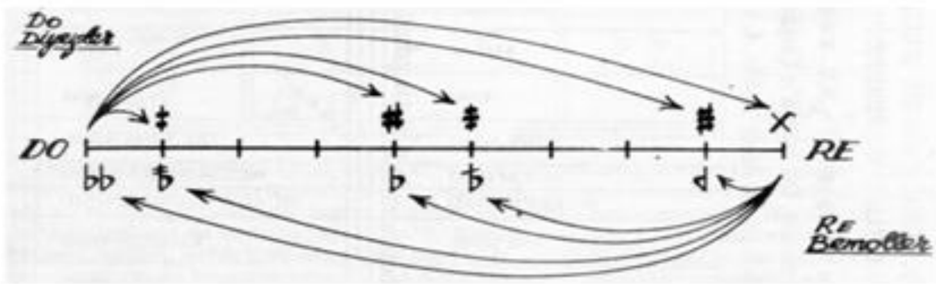


Figure 2.7. Display of the 9 intervals between two notes

Figure 2.8. Names of the tones used in Turkish Classical Music and their indicators

Another important distinction between Turkish music and western music is the use of octaves. While subsequent octaves in western music only differ in pitch, meaning that they can be analyzed together in terms of musical characteristics. On the contrary in Turkish music, notes of different pitches are usually named individually, such as a G4 note is named “Rast” while a G5 note which is an octave higher is called “Gerdaniye” (Bozkurt, 2008). Western music uses key signatures as a fundamental component to define major and minor scales, whereas Turkish music refers to melodic movement (seyir) and the chords included in the seyir just as much as it refers to the key signatures in the pieces composed (Akkoç, 2002).

The term “makam” can be described as a series of rules put together that assures the music to progress in a form of introduction, body and conclusion. These rules are called seyir. Makams cannot be changed by composers and seyirs prevent makams to become a random series of sounds. It is known that in TCM there are makams with different seyirs even though they have the same sequences (Tanrıkorur, 2011). The difference between two makams can usually be a slight change of one sound in a tone, therefore the definite sizes of certain intervals are of utmost importance. Musicians have generally gone into dispute due to the small tonal differences in similar sequences in TCM (Signell, 2006). As mentioned before, sounds in TCM are composed of 9 intervals between notes called komas. Hundreds of makams have been written with the koma intervals and every makam has its own unique quality. Another aspect of TCM is the authentic rhythm system in which the patterns are called “usül”. These musical diversity points out to the richness of the Turkish makam system (Say, 2002).

Makam aims to define the relationship between the “durak” pitch and “güçlü” pitch (which are the two most important tones in a makam) in a sequence. Makams are used in three different forms in terms of seyir (Özkan, 2013):

1) Ascendant seyir *2) Descendant seyir* *3) Ascendant – descendant seyir*

In Turkish music there are three different kinds of makam (Bingöl, 1999):

1) Main makam *2) Şed makam* *3) Unified/composite makam*

Ascendant seyirs can be defined when a song initiates with a durak pitch and continues in the low tones, halting in the güçlü pitch and advances in higher tones, coming back to the low tones and ending with the karar pitch. Descendant seyirs are the same, only this time instead of moving from low tones to high tones, it descends from high tones into low tones. In ascendant – descendant seyirs, the song starts in the güçlü pitch and proceeds on to low and high tones. After suspending over in güçlü pitch it returns to low tones and high tones, finishing with the karar pitch (Bingöl, 1999).

Table 2.5. *Makams used in Turkish Classical Music*

Main Makams	**Şed Makams**	**Unified Makams**	
Çargah	Acemaşiran	Hüzzam	Gerdaniye
Buselik	Mahur	Segah	Gülizar
Kürdi	Sultan-ı yegah	Nikriz	Şehnaz
Rast	Ruhnevaz	Nev-eser	Ferahfeza
Basit Süz-nak	Nihavend	Saba	Bestenigar
Uşşak	Ferahnüma	Irak	Bayatiaraban
Hüseyni	Aşkefza	Eviç	Isfahan
Karcığar	Kürdilihicazkar	Ferahnak	Zavil
Neva	Şedaraban	Nişaburek	
Hümayun	Süz-i dil	Acem	
Hicaz	Evcara	Acemkürdi	
Uzzal	Hicazkar	Muhayyerkürdi	
Zirgüleli Hicaz	Zirgüleli Süz-nak	Sazkar	

Some of the makams used in TCM are presented in Table 2.5. above. Main makams are created by adding together an exact tetrachord and an exact pentachord, or vice versa. They are displayed including an octave. A güçlü pitch is used to fuse together the tetrachord and pentachord. Main makams start with one of the three tones; Çargah, Rast or Dügah. Main makams have 13 different types. Şed makams are written by moving the scale of a main makam without breaking its pattern. These are also called "göçürtme" makams. Finally, unified or composite makams are formed by blending together different makam styles. Unified makams are examined in 8 groups, depending on their karar pitch. (Aybars, 2008).

Instruments used in Turkish music can be defined under 3 categories: percussions, woodwinds and strings. Percussions can be divided into 3 sub-categories which are wood percussions, cymbals and leather percussions. Woodwinds can be examined as bolted or unbolted. Lastly, string instruments are examined by bow-strings and pick strings (Tanrıkorur, 2011). A list of figures of Turkish instruments is presented below in Figures 2.9., 2.10. and 2.11.

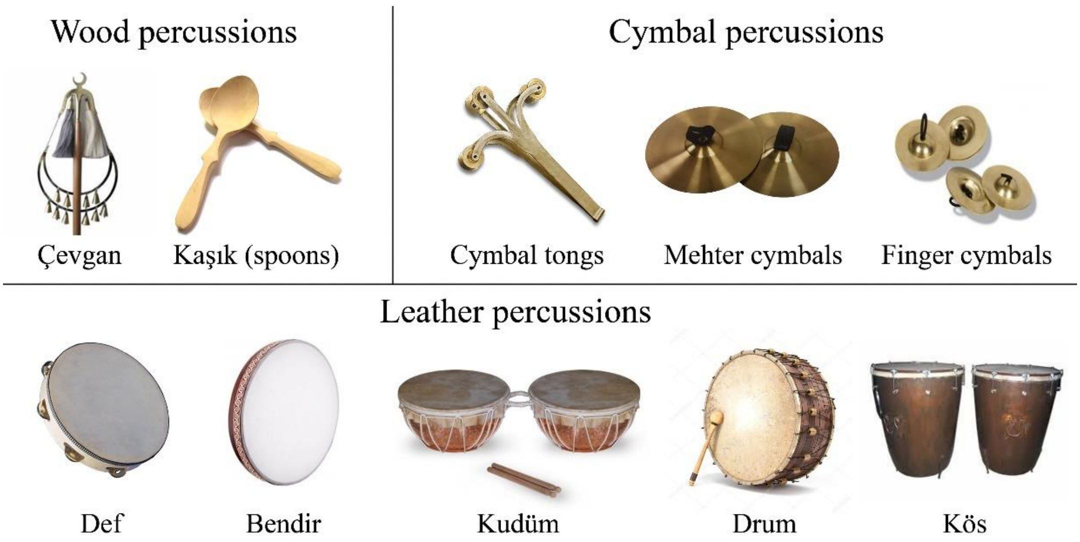


Figure 2.9. Percussion instruments used in Turkish music

Turkish classical music also deviates from western music in its form of education. While western music was written down on paper in the form of notes, Turkish music used to be passed down from teacher to student and had not started being written down up until the mid-18th century. This form of teaching music by memory and ear is called "meşk" and it has been used as a traditional method for centuries, even being preferred after the written form was introduced (Behar, 1993).

Figure 2.10. Woodwind instruments used in Turkish music

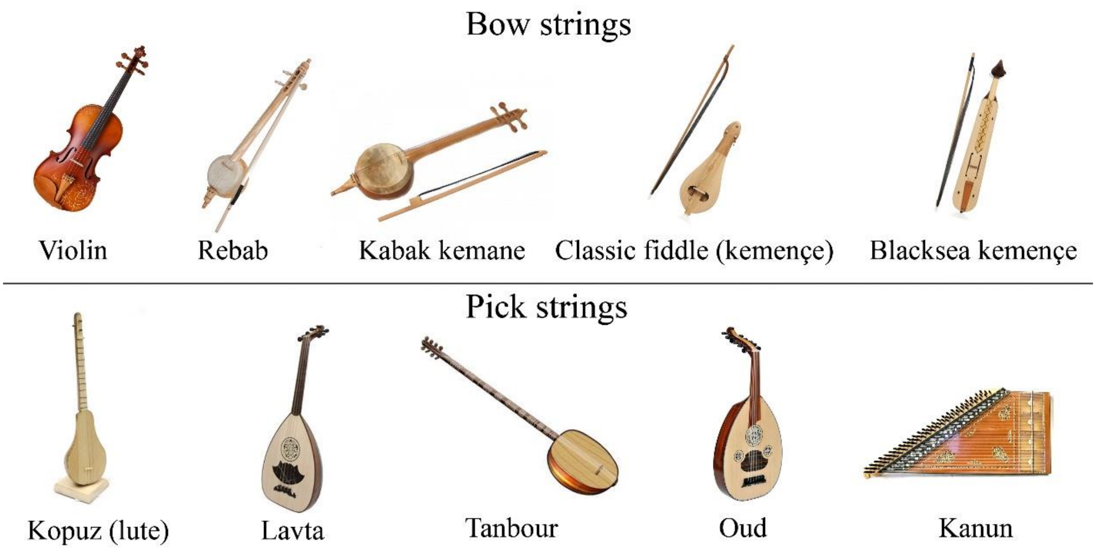


Figure 2.11. String instruments used in Turkish music

The meşk method consists of the teacher playing a certain Turkish music piece to the student and the student repeating it until they stop making mistakes. The teacher would start by only repeating the usül part and once the student had learned the usül, in other words the rhythmic beat patterns; the teacher would then move on to the actual song (Behar, 1998). Behar states that learning the usül is an essential part of memorizing a

Turkish song, because each song has their own particular usül and cannot be played with another usül, thus once an usül is memorized, it is easier to associate other aspects of a song such as makam and lyrics. It is also believed that Turkish music can only be performed perfectly with the meşk system and reading from notes would never be the same as learning from someone who has mastered the art form to its core (Sezgin, 1982). Citing music from paper is also considered to cause a lack of emotion, personal interpretations and enthusiasm, whereas a performer immerse themselves when playing by memory and create a much more intimate music as a result (Yavaşça, 1981).

CHAPTER 3

THEORIES AND POSTULATE

As previously explained in Chapter 2, TCM has certain differences from western classical music. It uses different kinds of traditional instruments. While western orchestras are mainly composed of string sections, brass sections, percussions and the piano; instruments like the tambour, kanun, oud, bağlama and bendir are the common key instruments of TCM. Western classical music is often polyphonic, whereas TCM almost always deals with monophony. Opera on the other hand, has a slight similarity to TCM because of the fact that both music styles may include vocals.

In order to establish a strong argument on whether TCM needs different acoustic conditions or not, an analysis showing the differences of objective values between TCM and other types of music is required.

In this chapter, the three aforementioned music styles are compared in terms of:

- Frequency spectrum
- Musical structure
- Dominant elements
- Musical components

For this analysis, a sample of 100 songs have been selected for each type of music: TCM, western classical music and finally, opera. These songs are then analyzed using an audio-visual software called Sonic Visualiser. The software is free to download from its official website, and it provides the user with visual data of the audio such as waveform graphs and spectrograms (Cannam et al, 2010).

The songs have been selected according to their capability of reflecting their music style, and of their commonness; in other words, popularity.

3.1. Frequency Spectrum Analysis

As mentioned before in Chapter 2, sound travels in waveform and its wave length changes depending on its pitch. Natural sounds have different frequencies inside them and the timbre depends on the correlation between the frequency gaps. When inspecting a sound, we need to determine its frequency spectrum in order to imagine how it would sound like to the human ear. Could a note played from a string instrument be coming from a cello, or from a violin? By looking at the note's frequency spectrum, we can guess which instrument had created the sound.

Frequency spectra provide us with power levels relevant to the frequency. Ladefoged (1995) explains that by applying a Fourier analysis to a soundwave, a frequency spectrum is formed. In Figure 3.1. below, the waveform of a C note played on the piano can be seen, followed by the frequency spectrum of said note in Figure 3.2. (Ladefoged, 1995). The top figure shows that multiple different vibrations create one wave, which forms the characteristic sound of a piano. In the bottom figure, sound level distributions according to each frequency band can be seen.

Just like frequency spectra, spectrograms allow one to visually examine audio components by transcribing sound data into graphs (Johnson, 2012). The difference between a spectrum and spectrogram is the presence of the time factor, Johnson states. While a spectrum can show power levels in a single time unit, a spectrogram illustrates the temporal changes in spectra. If we were to put it into simple words, we can say that a spectrogram is the "picture" of a sound.

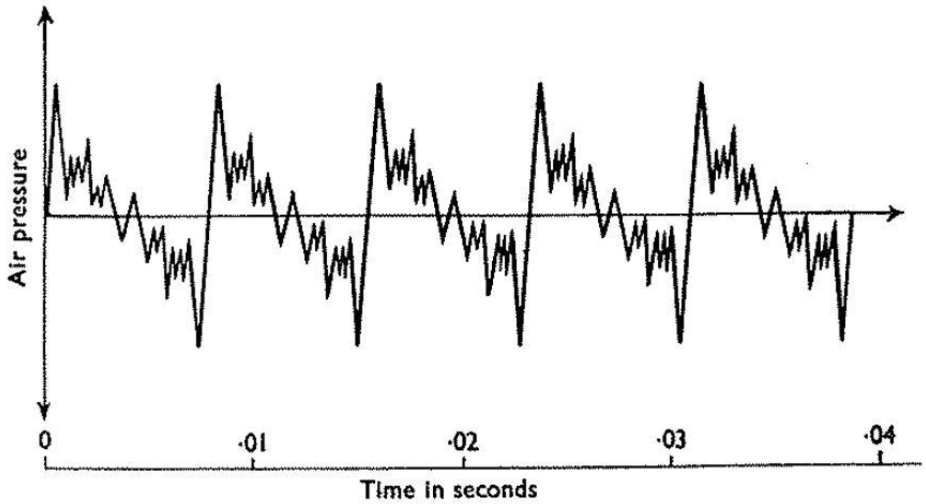


Figure 3.1. The waveform of the C note on the piano (Ladefoged, 1995)

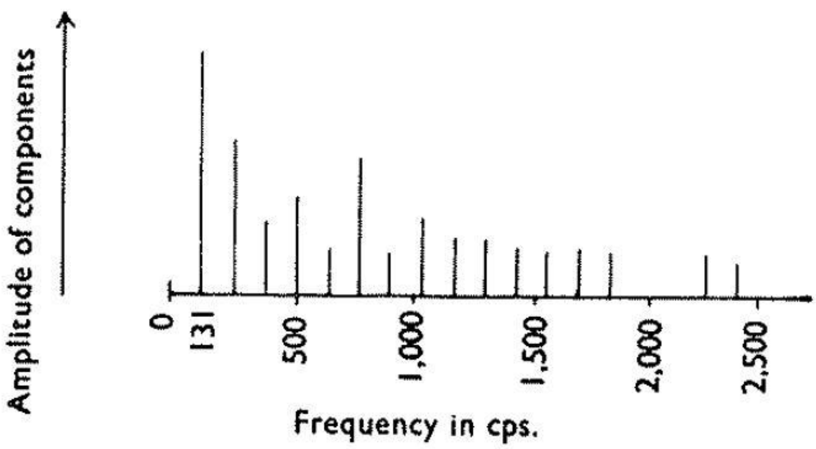


Figure 3.2. The frequency spectrum of the C note on the piano (Ladefoged, 1995)

3.2. Reading and Interpreting Spectrograms

In order to analyze spectrograms, one must first know how to read them. When we look at a spectrogram, there are three things to notice. First is the time component, which shows the changes of power levels of the frequencies in time (Stevens, 1999).

Time is usually represented in the horizontal axis of the spectrogram and goes from left to right (Ladefoged, 2010). The second thing to be aware of is the distribution of power levels. Spectrograms can be black and white or colored, but they work the same way. Black represents areas that have sound and white represents no sound, just as one color represents sound and another, no sound (Johnson, 2012). Finally, the third thing one should look out for when reading a spectrogram is the frequency, which is usually shown in the vertical axis (Ladefoged, 2010). Even though this is not all there is to reading a spectrogram, which requires expertise, one can interpret a spectrogram by looking at said three variants.

As mentioned before, for this study, three different musical styles were analyzed in order to see if there are any distinctions between their spectral values. A hundred songs each representing their own musical style, Turkish classical music, western classical music and opera, were selected and spectrograms were created for each song. The spectrograms were created using an audio visualizing software called Sonic Visualiser, created by Chris Cannam, Christian Landone and Mark Sandler in 2010 for, in their words: "musicologists, archivists, signal-processing researchers and anyone else looking for a friendly way to take a look at what lies inside the audio file". The software takes audio files and generates different kinds of spectrograms for the user to view. For further information on the software, please refer to the software's official website.

Before going into the analysis of the selected songs from three different styles, an example on reading a spectrogram is considered to be a better start. Below, two different sounds are demonstrated in waveform and their relevant spectrogram. A bird's chirping noise is shown in Figure 3.3. and a male person saying the word "hello" is shown in Figure 3.4.

In the top halves of the figures, the waveform analyses show us the sound levels as the bird sings and the man speaks. In the bottom halves, the spectrograms show us the sound frequency distributions by color. We can see here that in the spectrogram view of Figure 3.3., the bird has a distinctive sound that has more dominant sound power levels in frequency ranges between 4000 – 8000Hz (indicated in orange) and a slightly weaker one between 10000Hz and 16000Hz (indicated in bright green) in the first two chirps, followed by the third chirp which now has four different areas with an incursion of 1000 – 4000Hz followed by three other frequency gaps.

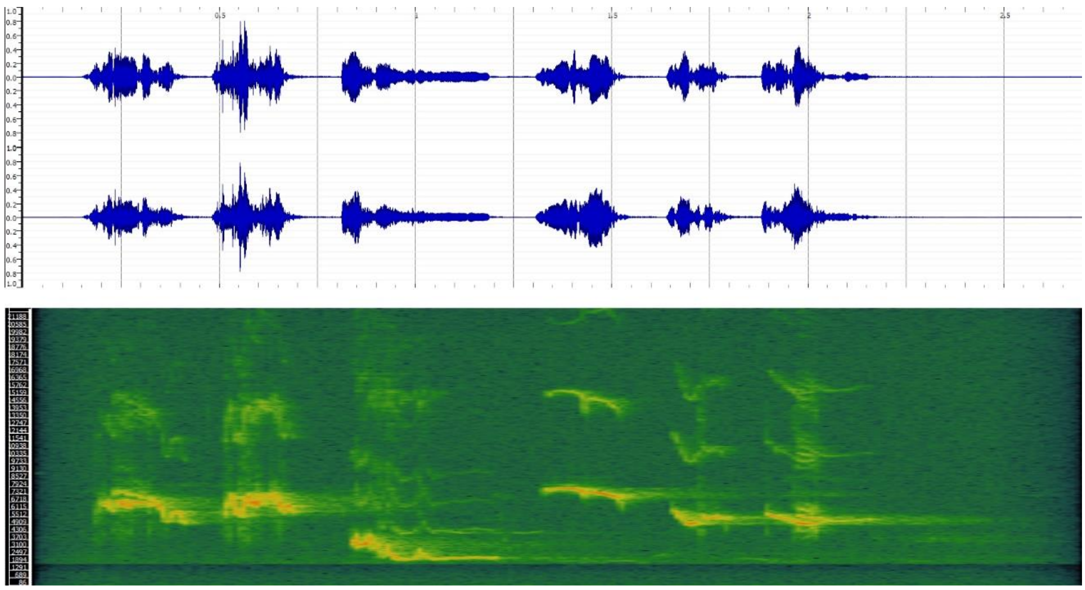


Figure 3.3. Bird chirping, (top) waveform graph, (bottom) spectrogram

The man's voice, on the other hand, is clearly different than a sound of a bird. It is seen in Figure 3.4. that the word "hello" is vocally more continuous than the rapid, momentary sounds that follow each other when the bird sings. Here in the man's spectrogram, we see that the power levels are distributed almost evenly as he begins with the first vowel "h", however as he moves on to finish the syllable which ends with "e" and continues with the "-lo" sound, the dominant frequency instantly shifts to a lower range indicated with orange and red between 10Hz and 1000Hz. We can also see that as he says "l", there are visible frequency gaps indicated with dark green (which acts the same way as of a white area in a black and white spectrogram) approximately between 1000 – 4000Hz, 5000 – 6000Hz and 12000 – 16000Hz. By reading these two spectrograms, we can identify the distinctions between sounds and how they behave. Stevens (1999) has used spectrograms to identify human speech patterns in the field of linguistics and phonetics. In this study, the same principle is applied in an attempt to distinguish Turkish classical music from other types of music in terms of acoustic properties.

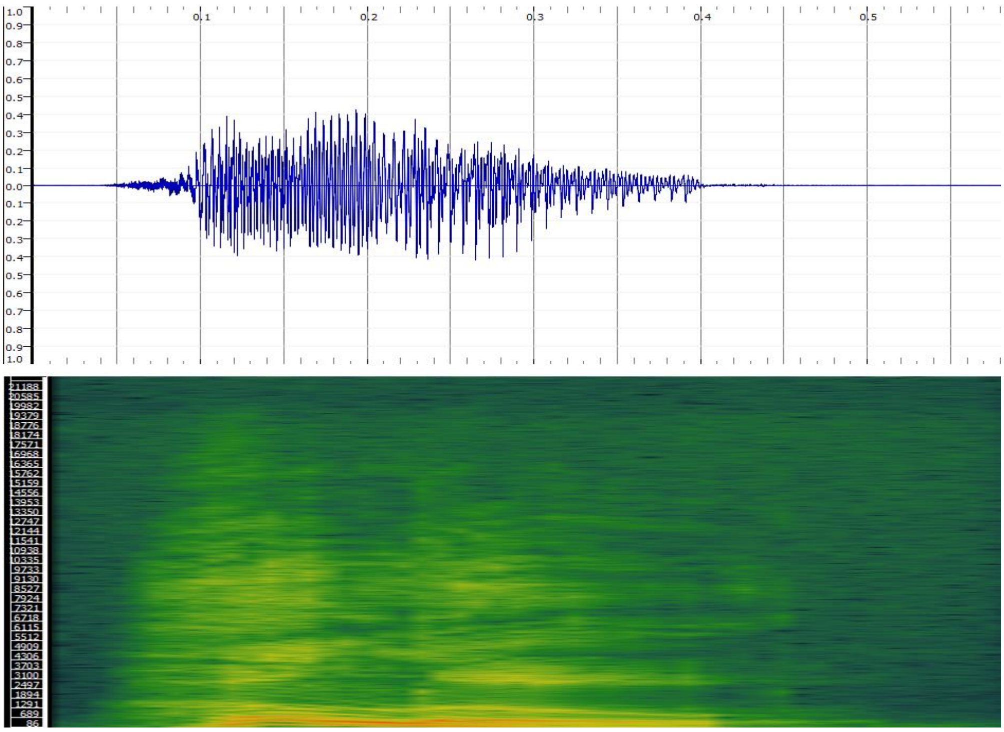


Figure 3.4. Male saying “hello”, (top) waveform graph, (bottom) spectrogram

3.3. Analyses of Selected Songs

After a brief example of how spectrograms can be interpreted, it is now time to move on to the analyses of the selected songs of three different musical styles. While a total of 100 songs have been analyzed for each type of music, fewer examples that are considered to be enough will be given here in this chapter. A full list of figures of the spectrogram analyses of the songs can be found in the Appendices section of this thesis.

3.3.1. Analyses for Turkish Classical Music

First off are the spectrogram views of songs produced in the Turkish classical music style. The initial point to notice is that TCM songs tend to follow a distinct pattern. The songs usually do not have a point of climax or a breakdown, changes in tempo/ rhythm or crescendo/decrescendo moments. The typical structure of a TCM song is basically composed of an intro, followed by two verses connected with a chorus part, and an ending with the repetition of the chorus.

Below in Figure 3.5. are three examples of Turkish classical music pieces. The first one (a) is a rendition of "Dediler Zamanla Hep" performed by one of the most appreciated TCM singers of the time, Zeki Müren and is 4 minutes 7 seconds long. Following that (b) is the song "Ada Sahilleri" interpreted by TCM orchestra Fasl-ı Beyoğlu re-recorded in 2014, with a length of 6 minutes and 1 second. Lastly, the third example (c) is "Seni Sordum Yıldızlara" again, performed by Zeki Müren, recorded in the year 1989, and is 5 minutes 9 seconds long.

a) b) c)

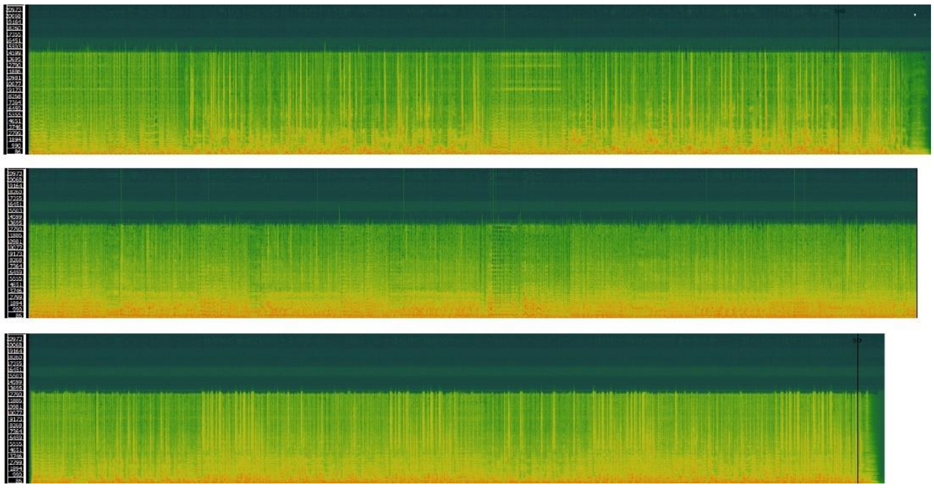


Figure 3.5. a) Spectrogram view of "Dediler Zamanla Hep", performed by Zeki Müren (1989)
b) Spectrogram view of "Ada Sahilleri" performed by Fasl-ı Beyoğlu (2014)
c) Spectrogram view of "Seni Sordum Yıldızlara" performed by Zeki Müren (1989)

If we were to inspect the three spectrograms below, the first thing that catches our attention is the top frequency "line". As seen in Figure 3.5., a noticeable "border" seems to cut through the spectrogram, and there seems to be a limit to the frequency ranges that are used in TCM songs. This limit has been seen to go upmost to 15000Hz, as seen in Figure 3.5. (a). At first, this was considered to be a recording related issue, due to most TCM music was recorded on vinyl and the quality of the recordings were insufficient to capture higher frequencies. However, as more recent examples were reviewed, such as in Figure 3.5. (b), it was understood that due to the instruments and makams of TCM, high pitch notes were rarely used. Some examples such as in Figure 3.6 turned up to show even lower frequency borders. In the song "Lale Devri" by Sezen Aksu, recorded in 2009 which is 4 minutes 56 seconds long, it can be seen that the visible border line lies somewhere around 8000hz.

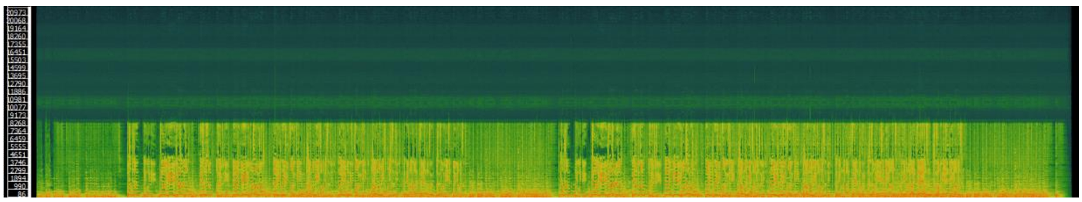


Figure 3.6. Spectrogram view of "Lale Devri" performed by Sezen Aksu (2009)

Going back to Figure 3.5., we can see that the dominant frequencies are in the lower frequency range, at around 2000Hz for "Adalar Sahilleri" (b) and 1000Hz for "Dediler Zamanla Hep" (a) and "Seni Sordum Yıldızlara" (c). This is due to the percussion instruments and the significance of rhythm in TCM. The green areas scattered evenly throughout the songs are the instrument sections, mainly string instruments; the violin, kanun and the oud, to be more specific. These seem to have frequency ranges all the way from 2000Hz to 16000Hz. The yellowish-green frequency "spikes" are the parts where vocal is involved and mostly when they are pronouncing the "s" vowel or other hard vowels such as "ş", "ç", "t" and "z". Looking at these spikes, it is possible to observe how and when the vocal parts of the songs come into play and how much of an importance the presence vocals possess in TCM.

As said earlier, the music pieces would be analyzed in three different categories: frequency spectrum, musical structure and element dominance. Thus, to sum up;

- Turkish classical music has a wide and fairly-distributed spectrum pattern. While the peak sound levels are observed to be in the lower ranges around 1000 – 2000Hz, overall frequency distribution seems to be homogenous. TCM pieces tend to have a border line indicating their frequency limit, which can go up to 15000Hz.
- TCM songs have a tendency to follow a common musical structure. There are no apparent changes in the song progression and the general texture of a song is kept intact in practically every scenario.
- Vocals and percussions are considered to be essential elements in TCM due to their higher presence and even though string instruments cover a larger area in the spectrograms, the high presence of vocals and percussions should be looked out for in terms of acoustic design.

3.3.2. Analyses for Western Classical Music

After a brief analysis of Turkish classical music spectrograms, next up is inspecting the spectrograms of western classical music pieces. Unlike TCM, western classical music originated in the early 19^{th} century and has had many different composers with many different influences that changed its movements unique to their relative eras. Thus, western classical music cannot be broken down to one single type of musical structure. However, as various styles were analyzed within the 100 selected pieces, the presence of distinct differences from that of TCM were observed. A full list of pieces can be found in the Appendices section of this thesis.

First of all, as opposed to TCM, western classical music does not follow a recognizable pattern. Rather, it is full of changes in rhythm, tempo, accents and use of instruments. Despite the fact that some of the examples consisted of a single instrument, such as Ludwig van Beethoven's Moonlight Sonata, where the piece was written for the piano only, the majority of the pieces were performed by a symphony orchestra, hence including a string section, a brass section, percussions, woodwinds and a piano or a harpsichord. Exceptions where there is a single instrument or fewer instruments are to be analyzed individually later on in this section.

In Figure 3.7. three examples of western classical music are presented in spectrogram view. The first example (a) is "Les Toreadors" written by Georges Bizet in 1875 for the "Carmen" opera, with a length of 2 minutes and 19 seconds. Later, the next example (b) is "Concerto Grosso" by George Frederic Handel in 1739, which is 10 minutes 53 seconds long. The third and final example (c) is the instrumental overture piece from the "Don Giovanni" opera written by Wolfgang Amadeus Mozart in 1787 with a length of 6 minutes and 11 seconds.

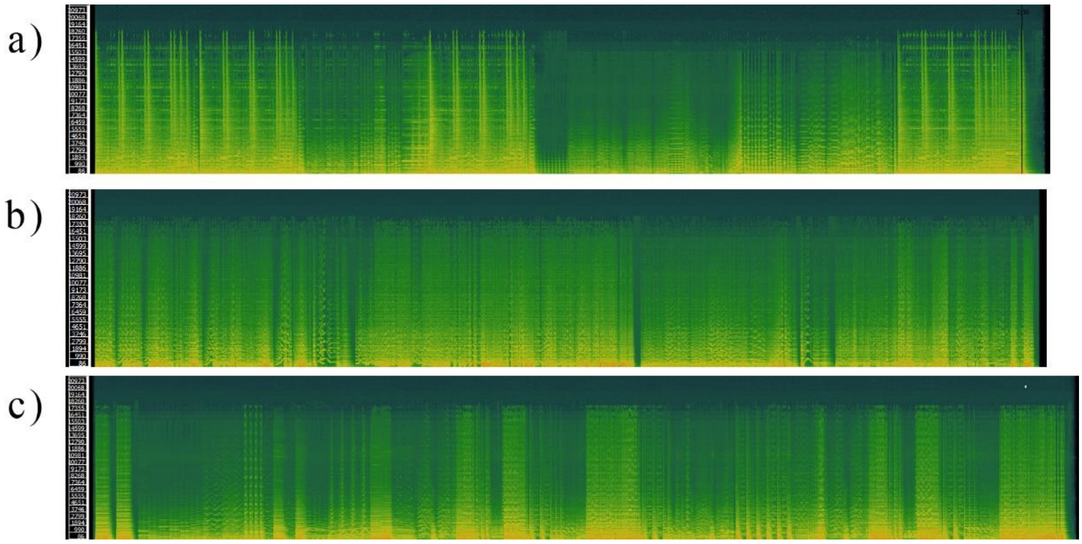


Figure 3.7. a) Spectrogram view of "Les Toreadors" from "Carmen" (Bizet, 1875)
b) Spectrogram view of "Concerto Grosso in A minor op. 6 no. 4" (Handel, 1739)
c) Spectrogram view of "Overture" from "Don Giovanni" (Mozart, 1787)

Now, let us recall the three spectrogram examples that were given in Figure 3.5. in the Turkish classical music section. In TCM, the spectrograms showed an ongoing frequency limit on every piece, with the limit reaching an utmost 15000Hz on some examples and lower limits up to 8000Hz were observed. In opposition, it can be seen on Figure 3.7. above, that in western classical music, the so-called “border lines” are no longer in play compared to TCM. Instead, power spikes can be seen throughout the spectrogram, eliminating the visual frequency border and creating a vivid, dynamic and changing pattern. This is due to the nature of western classical music having different parts and instruments within a piece.

If we were to look at the first example in Figure 3.7. (a), a total of six pattern changes are visible throughout the piece. A more detailed representation is shown in Figure 3.8. below. Just as with TCM, here, the spectral changes in power levels throughout time point out the progressions during the piece is performed. In the first pattern (1), the frequent power spikes represent cymbals being hit, while in the background, the string and brass sections play a tune. The power spikes cover an area reaching up to 18000Hz in frequency and in between, the frequency spectra can be read to show that notes are being played, taking the form of octave bands in the spectrogram. In the second part (2), it is visible that the cymbals have stopped playing. Now, the power levels are slightly stronger in the lower frequencies; however, the overall scatter of power is even and the octave bands can be spotted clearly. The third part (1’) is a repetition of the first part, but this time, the power levels are shown in brighter colors, indicating that this part is played stronger than its previous variant. The following

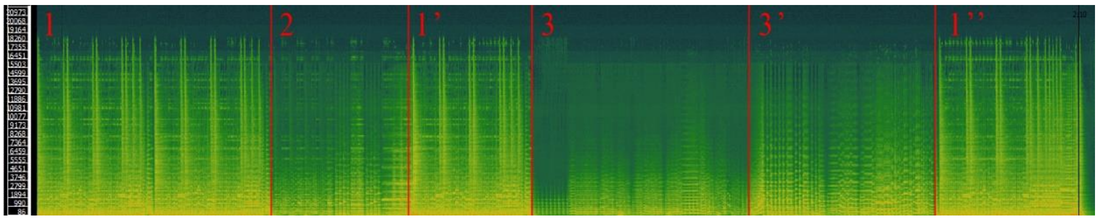


Figure 3.8. Spectrogram view, breakdown on “Les Toreadors” from “Carmen” (Bizet, 1875)

section (3) is played more softly, as it can be seen on the spectrogram. In the beginning of section 3, string instruments can be seen playing a single note, afterwards, a melody is played along with the other instruments in harmony. Continuing with the next part (3'), the same pattern is repeated but again, with stronger accents this time. Here the difference in power levels can be observed more clearly, as the bright green areas in the lower frequencies change into bright orange and the dark green parts become brighter green. The last part (1'') is the closure part which is again, the repetition of the opening section. Here, the cymbals are back in play and as the piece reaches its end, they become more frequent, as the power spikes become frequent with them.

As mentioned earlier, it is possible to read notes being played by noticing octave bands in spectrograms. In Figure 3.8., an orchestra playing notes in unity can be seen. In order to achieve a better understanding, a clearer, zoomed in example of notes represented in octave bands has been given in Figure 3.9. At 8 minutes and 5 seconds into "Concerto Grosso" by Handel, a solo violin plays the notes in a C major scale, and even though determining which note is being played requires expertise, or listening to the song while inspecting a spectrogram, one can with ease observe pitch

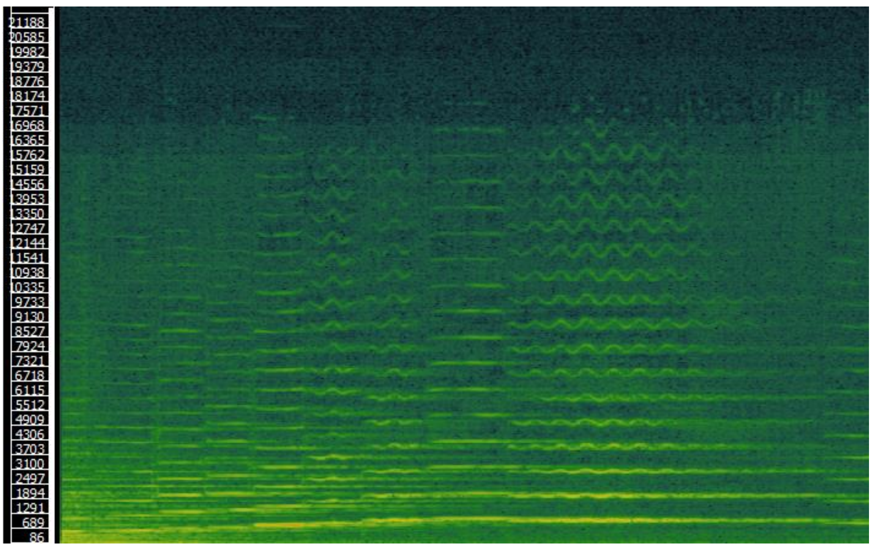


Figure 3.9. Spectrogram view of the octave bands produced by a solo violin playing a C major scale, from "Concerto Grosso in A minor op. 6 no. 4" (Handel, 1739)

changes just by looking at the spectrogram above in Figure 3.9. Furthermore, the presence of the octave bands points out to the fact that a musical sound is being produced, which serves as a guideline in distinguishing speech from music.

Earlier, it has been apprehended that power spikes in a spectrogram can be interpreted in different ways. The Turkish classical music examples showed that the spikes can point to vocals, and the western classical music examples revealed that instant, loud sounds such as cymbal blasts may refer to the cause of power spikes. One thing in common between these two examples is that these power spikes cover up a large range of the frequency spectrum and as the name suggests, are powerful, hence loud to the human ear. Although one may not be able to detect what kind of sound is being produced, an important thing to note is to keep in mind the characteristics of said power spikes. Below in Figure 3.10., the first 37 seconds of the piece "Also Sprach Zarathustra" by Richard Strauss is demonstrated in spectrogram form. As the song builds up, lower frequencies become more visible, again creating octave bands pointing out that a musical note is being played. Afterwards, two power spikes indicated by orange in lower frequencies and bright green in higher, are formed, followed by 13 shorter spikes. The first two represent a brass section playing two subsequent notes, in which the octave bands are still visible within the duration of the

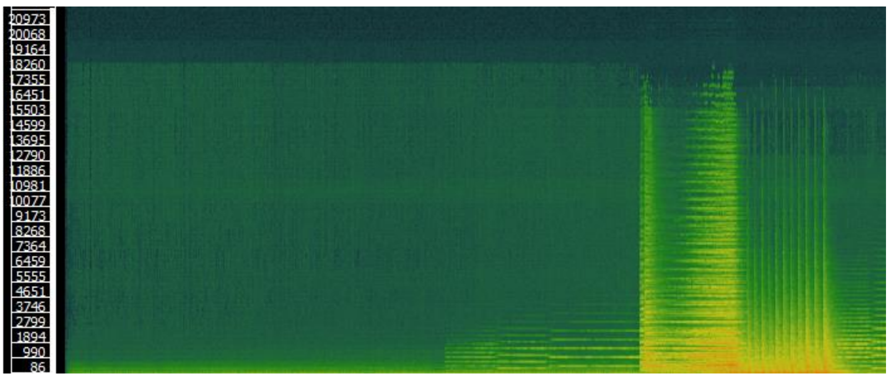


Figure 3.10. Partial spectrogram view of "Also Sprach Zarathustra, op. 30" (Strauss, 1896)

note. The following 13 spikes are the hits of a bass drum. This time, octave bands are harder to notice due to the drums nature of producing musical sounds mixed with non-musical sounds, or noise. Putting these together, it can be said that power spikes in spectrograms can originate from different sources, but they represent sudden and loud sounds, in particular.

Next are the analyses of spectrograms that belong to pieces with only one instrument in them. For this, three examples of piano compositions have been selected. Spectrograms of the full piece along with detailed close-up sections are used for this part in order to get a better look at what is taking effect throughout the musical pieces.

The first piece selected is “Fur Elise” by Ludwig van Beethoven written in 1810 for the piano, having a length of 2 minutes and 53 seconds. Secondly, “Moonlight Sonata” written by Ludwig van Beethoven in 1801 was used, which is 5 minutes and 27 seconds long. The last piece selected is “The Merry Peasant” by Robert Schumann written in 1848 which is 54 seconds short. All three pieces are played on the piano.

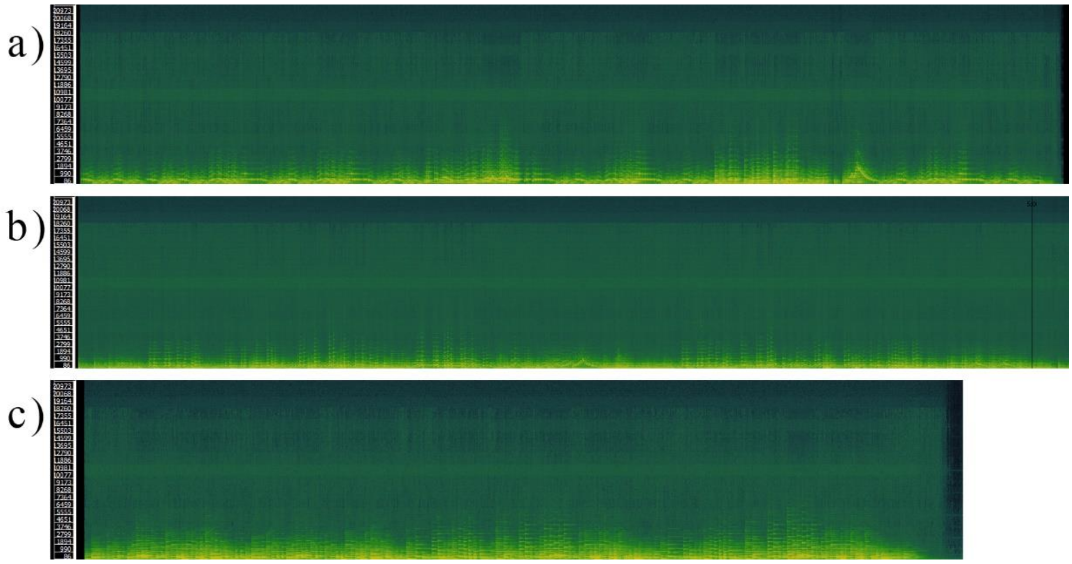


Figure 3.11. a) Spectrogram view of “Fur Elise” (Beethoven, 1810)
b) Spectrogram view of “Moonlight Sonata” (Beethoven, 1801)
c) Spectrogram view of “The Merry Peasant” (Schumann, 1848)

Figure 3.11. shows the spectrogram views of selected classical pieces. Below is a close-up view of "Fur Elise" during the 10 seconds between 1 minute 15 seconds and 1 minute 25 seconds, presented in Figure 3.12. Looking at Figure 3.11., the frequency spectra are largely distributed ranging from lower frequencies to the middle frequency zone up to 8000Hz at some points in (a), 4000Hz in (b) and around 6000-7000Hz in (c). However, power levels are slightly higher in the lower range between 0 – 2000Hz. This means that when dealing with the piano only, the sound propagation in lower frequencies become of significance in terms of acoustic design. Following after with Figure 3.12., once more, octave bands are easily observable allowing one to notice a musical sound is being produced, and again, pitch changes are easy to observe.

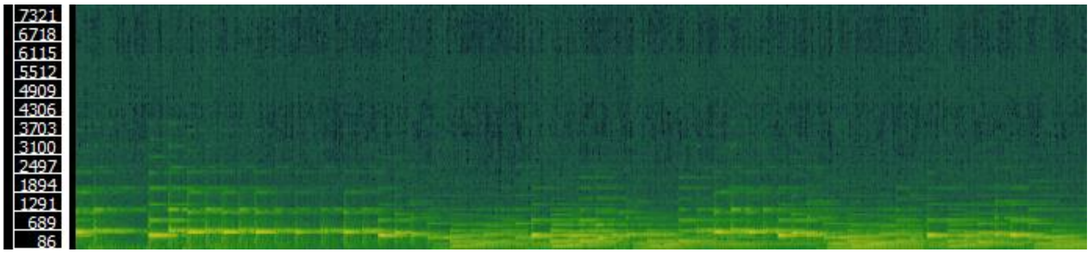


Figure 3.12. Partial spectrogram view of "Moonlight Sonata" (Beethoven, 1801)

After the analyses of western classical music pieces are finished, assumptions may be given in terms of frequency spectrum, musical structure and element dominance:

- In contrary to Turkish classical music, western classical music does not commonly have a homogenous distribution in frequencies. The frequency "border" that was observed in TCM pieces is no longer present and octave bands can be observed. Frequency ranges can go up to 18000Hz.
- The musical structure is not stable like in TCM where it used to be. Musical pieces tend to progress in time and seem to have various different parts where changes in tempo, instruments and accents occur, causing changes in frequency spectra and overall loudness.

- Just like the musical structure, dominant elements change according to the progression in the songs. String sections can follow brass sections and the whole orchestra can play together in harmony. However, when certain instruments are about to play solo, the behavior of said instruments should be kept in mind when it comes to acoustic design.

3.3.3. Analyses for Opera

The final analyses of this section are of the selected pieces in the opera style. Once again, 100 examples of opera music were analyzed in spectrogram view. The pieces were selected to reflect the overall history of opera. A full list of opera pieces can be found in the Appendices section of this thesis.

In the previous two sections, Turkish classical music and western classical music were analyzed. Before continuing with opera, a quick reminder of the analyses of TCM and western classical music might assist in the inspection of the opera pieces. As recalled, TCM had a distinct pattern in terms of frequency spectra and musical structure, whereas western classical music was more volatile. Opera on the other hand, lies somewhere in between these two styles of music.

Just like TCM, vocals are a crucial element of an opera and occasionally, there are multiple vocals or even a choir. This creates an essential necessity to be able to locate the position of individual vocals in order to distinguish who is singing on the stage during an opera. On the other hand, there is also a symphony orchestra in most operatic pieces, creating a similarity in certain aspects with western classical music. There are song progressions throughout an opera piece just as in western classical pieces. Since operas tell a story or an event via music and acting, the overall atmosphere tends to change according to the emotions that are reflected. Instruments might start playing louder or softer, there may be parts where the vocal sings solo or the instruments accompany the vocals with harmony, or some parts may even be solely composed of instruments, without vocals. In other words, opera can be considered a blend of the two previously analyzed musical styles, in terms of spectral behavior and acoustic characteristics. However, since it is neither quite similar to TCM or western classical music, additional inspection is required.

Three different examples showing different patterns in opera has been given in Figure 3.13. below. The first example is “Casta Diva” from the opera “Norma” written by Gentile Bellini in 1958, performed by Maria Callas with a length of 7 minutes 31 seconds. Following is from the “Pagliacci” opera by Ruggero Leoncavallo in 1892, named “Vesti la Giuba” performed by Enrique Caruso, which is 3 minutes 14 seconds long. Finally, “La Donna é Mobile” sang by Luciano Pavarotti from the “Rigoletto” opera is given as an example, which is 2 minutes 33 seconds long.

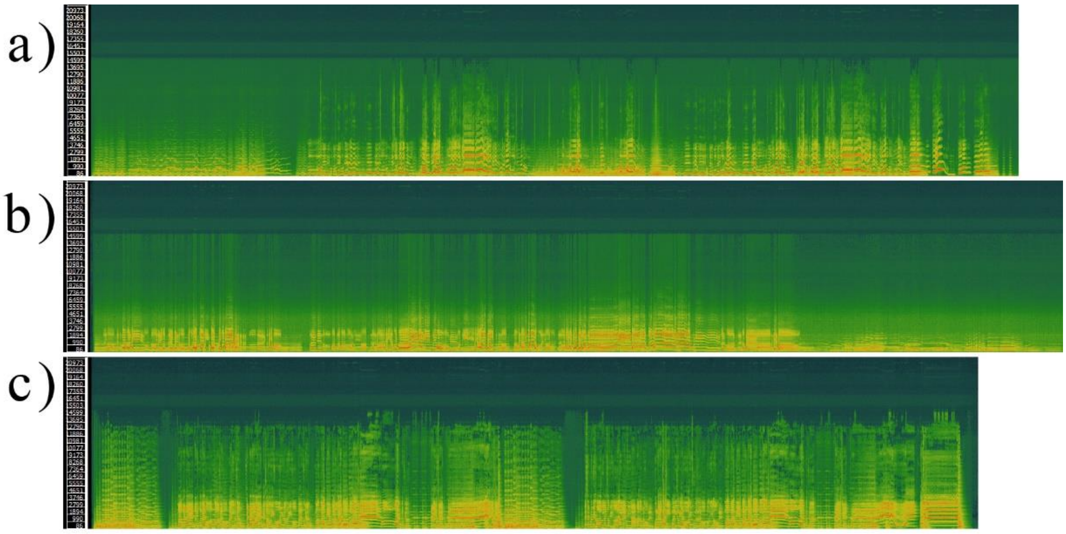


Figure 3.13. a) Spectrogram view of “Casta Diva” by Maria Callas in “Norma” (Bellini, 1958)
b) Spectrogram view of “Vesti la Giuba” by Enrique Caruso in “Pagliacci” (Leoncavallo, 1892)
c) Spectrogram view of “La Donna é Mobile” by Luciano Pavarotti in “Rigoletto” (Verdi, 1851)

With a first glimpse at the spectrograms, a few things can be noticed. Firstly, power spikes are visible throughout the musical piece just as in TCM and western classical music. In TCM, power spikes pointed out vocal progressions such as the pronunciations of consonants and in western classical music, power spikes could exist of various reasons like an increase in the accents or beats of a percussion instrument. In the examples above in Figure 3.13., the power spikes belong to both the vocal and orchestra, given that in opera, the orchestra and the singers accompany each other following a shared tune. It can be observed that lower-mid frequencies up to 4000Hz are higher in sound power levels since they are indicated by orange, and the frequency limit can go up to 15000Hz, being more similar to that of TCM.

Another matter observed in the spectrograms is that the octave bands become clearer and can be read throughout the piece in the case of opera music. This is due to the aforementioned fact that singers and instruments usually sing and play the same tune during an opera, unlike most cases in TCM where the singer sings a main tune and instruments act like a background fill while vocals are present. Below is a clearer example of visible octave bands recorded during a 15 second section of “Si, mi chiamano Mimi” performed by Renata Tebaldi from the opera “La Boheme” written by Giacomo Puccini in 1896.

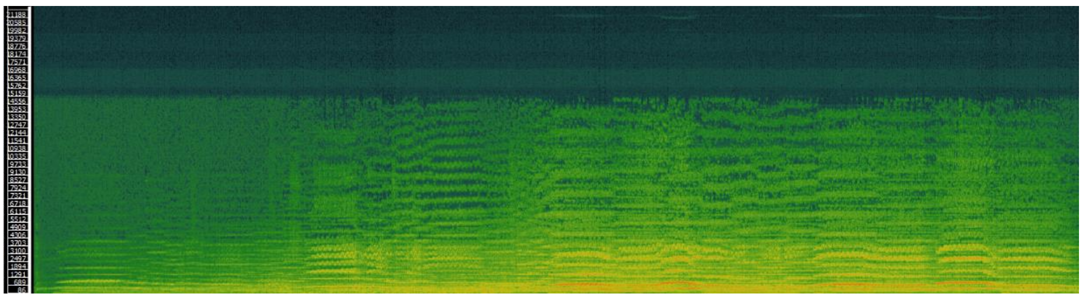


Figure 3.14. Partial spectrogram view of “Si, mi chiamano Mimi” by Renata Tebaldi from “La Boheme” between 3:05 – 3:20 (Puccini, 1896)

To finalize this section, outputs regarding frequency spectrum, musical structure and element dominance in the opera music style have been given below:

- Opera can be recognized in a place between Turkish classical music and western classical music. While not as uniform as in TCM, frequency spectra are not as dynamic as in western classical music, either. Power spikes are distributed evenly throughout pieces and can reach up to 18000Hz, whereas the highest sound levels are in the lower and middle range up to 4000Hz, being slightly similar to TCM.

- Similar to western classical music, opera has a versatile composition in terms of musical structure. Along with the addition of vocals to the roster, opera songs tend to tell a story and as the story progresses, the music changes accordingly in order to express different scenarios with different emotions.
- Although the dominance between the instruments may change depending on the progression of the pieces, vocals can ultimately be considered as the key element of opera. Thus, clarity becomes an important aspect to be wary of in terms of acoustic design.

3.4. Analyses of Musical Components

Inspecting the spectrograms of samples from each musical style informs about the basic aspects of each music. However, in order to fully comprehend the differences between each music and the distinct features of TCM, the musical styles need to be broken down into their basic components, which are the instruments, the singers and room acoustic parameters for each type of music. The instrument and vocal components of the music styles can be broken down as the following:

- For western classical music, an orchestra mainly composes of 4 different instrument groups: strings, woodwinds, brass and percussions.
- Strings are formed of 12 – 24 violins, which have the highest pitch, 8 – 12 violas, 6 -12 cellos and 2 – 8 basses with the lowest pitch out of all.
- Woodwind instruments also differentiate in their frequency range. The piccolo and the flute have the highest pitch, while the oboe lies somewhere in the mid

frequencies. The bassoon has a range in the low frequencies, and lastly, the clarinet is known to cover a wide frequency range, from low to high.

- Brass instruments have different ranges, as well as the other instrument groups. The highest pitched of all is the trumpet, while the French horn covers mid to high frequencies. The trombone has a range of low to mid frequencies. Lastly, the tuba has the lowest pitch which is in the low frequencies.
- Percussions can be divided into two groups as pitched and non-pitched percussions. Pitched percussions include instruments such as the piano, the xylophone, the marimba and the timpani. The piano can cover a wide range of frequency, while the xylophone and the marimba are usually in the mid to high frequencies. Non-pitched percussions comprise mainly of drums and cymbals. The snare drum has a higher frequency range than the bass drum, which has a bass sound with a range in the low frequencies. The cymbal sections provide high frequency sounds.

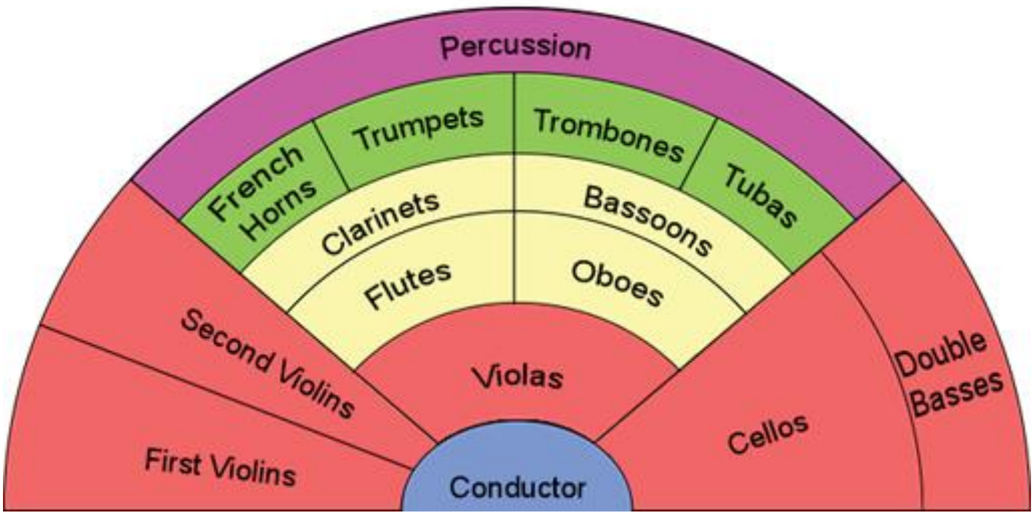


Figure 3.15. The basic components of a symphony orchestra

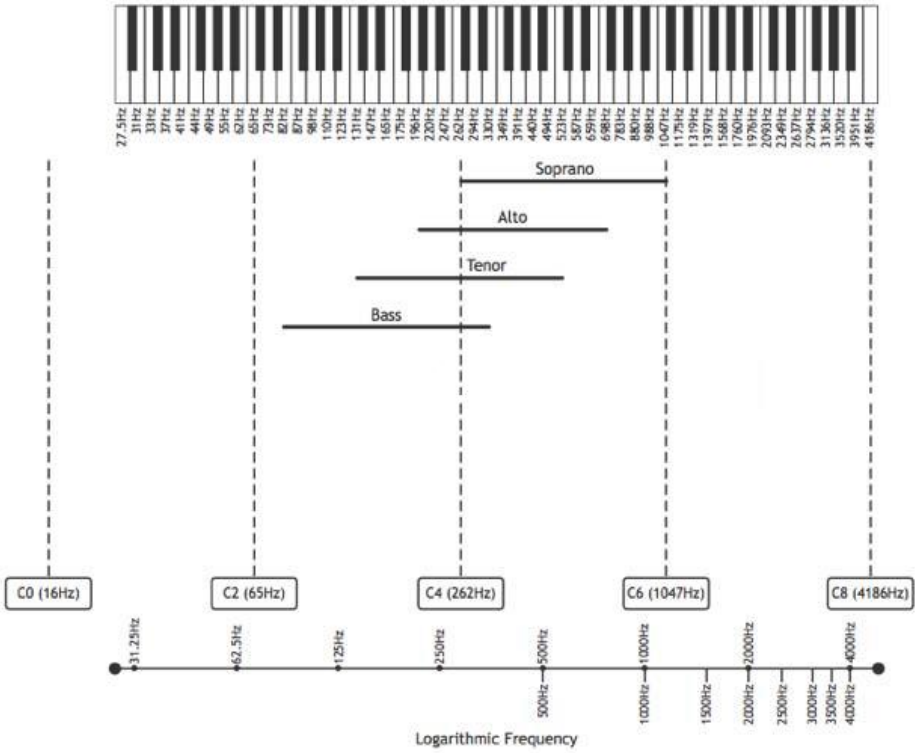


Figure 3.16. Frequency ranges of human voice

- Opera has the same instrument formation as classical music, with the addition of vocals. Vocals may provide a variety of different frequency ranges, depending on the vocal characteristics of the singers. Male vocals consist of tenors, baritones and basses, while female voices can be described as sopranos, mezzo-sopranos and altos.
- Male voice has a fundamental frequency range between 100Hz and 900Hz, and harmonics between 900Hz to 8000Hz. While tenor voices are commonly ranged between 125 and 500Hz, bass voices cover a range between 80Hz and 330Hz. Baritone voices lie between tenor and bass, and may cover a wide range from low to mid frequencies (Nadolezsny, 1923).
- Female voice registers have a fundamental range between 350Hz to 3000Hz, with a harmonic range of 3000Hz to 17000Hz. The soprano voice covers a gap between 250 – 1000Hz and the alto voice has a range of 195 – 700Hz. The mezzo-soprano is in between the soprano and alto (Nadolezsny, 1923).

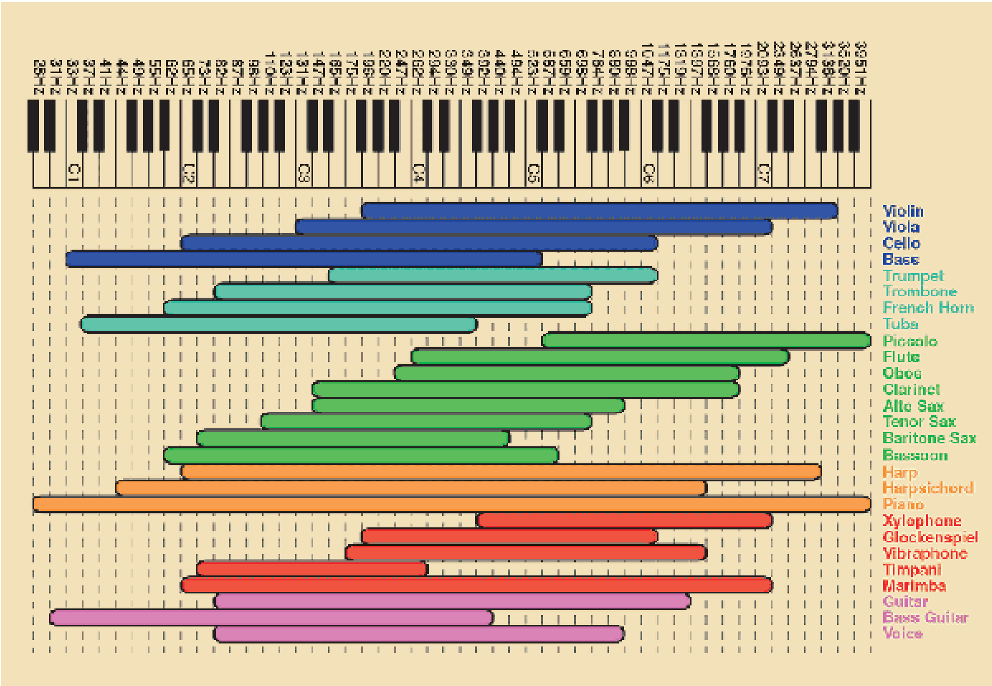


Figure 3.17. Frequency ranges of orchestral instruments

- In Turkish classical music, the instruments are different from that of a symphony orchestra, and the orchestra size is considerably smaller. The main instruments of a common TCM orchestra are the reed flute, bendir, tambour and kanun. Vocals are an essential component of TCM, however; unlike opera, vocals in TCM are mainly composed of soprano and tenor voices, and the presence of bass and alto voices are quite rare.
- The reed flute has a high pitch voice, being the highest pitched instrument out of all the main TCM instruments. Its frequency range is similar to a flutes, being in between 250Hz and 2500Hz (Kartal, 2012).
- The tambour is a string instrument that has a low-to-mid frequency range. It has a range between 80Hz and 1250Hz. It is commonly used with a kanun, which has a range of 3,5 octaves, between 80Hz and 500Hz
- The bendir is the main percussion instrument of TCM, and has a low frequency range between 60Hz and 250Hz.

Regarding the room acoustic parameters needed for classical music, opera and TCM; the specifications may be listed as follows:

- Western classical music is heard best in rectangular shaped rooms. The acceptable volume per listener is considered to be 8 to 11 cubic meters. The optimum reverberation times for classical music is between 1,8 and 2,2 seconds. Early decay time values that are more than 1,1 times the RT value is accepted as successful. C_{80} and D_{50} values are observed best between -4 dB and +4 dB, and 0,45 – 0,60 respectively. Bass ratios that are higher than 1,00 result in a better listening experience. For classical music, a BR value between 1,00 – 1,40 is considered acceptable (Beranek, 1996).
- Horseshoe shaped halls are commonly preferred for opera. For the room size, 6 to 8 cubic meters is considered to be acceptable. Optimum RT values are most successful results when in between 1,3 and 1,8 seconds. EDT values are best recognized between 1,40 and 1,75 seconds. C_{80}, D_{50} and BR values may be accepted the same for opera as to western classical music (Beranek, 1996).
- Turkish classical music is known to be performed in small rooms during the Ottoman period. There is limited information on the acoustic qualities of rooms where TCM was performed, and no widely-acknowledged standards for TCM acoustic parameters. Currently, parameters that are accepted for chamber music is considered feasible for TCM. However, further inspection and research on this topic is sought today. The acceptable RT value for chamber music is between 0,8 and 1,1 seconds. The C_{80} parameter is believed to be most successful between 0 and +4 dB. BR values between 1,1 and 1,2 can be considered favorable (Özçevik & Yüksel Can, 2015).

3.5. Discussion

This section covers the discussions and comparisons about the three types of music that were analyzed by the means of frequency spectra, musical structure, dominant elements and musical components. After the individual analyses of the music types, the next step is to inspect them together and make correlations between each other.

Table 3.1. *Outputs of the analyses of three musical styles in terms of frequency spectra, musical structure and dominant elements*

Type of Music	***Frequency Spectra***	***Musical Structure***	***Dominant Elements***
Turkish Classical	Static Limit: 15000Hz Peak: 1000-2000Hz	Stable	Vocals, percussion
Western Classical	Dynamic Limit: 18000Hz Peak: 2000-3000Hz	Versatile	Dependent instrument
Opera	Semi-dynamic Limit: 18000Hz Peak: 4000Hz	Versatile	Vocals

A brief summary of the frequency spectrum analyses is demonstrated in Table 3.1. In the table, the outputs of the analysis criteria are presented for each type of music. For instance, regarding frequency spectra, Turkish classical music is observed to be homogenous throughout the pieces, thus is indicated as static. The highest observed range of frequency is up to 15000Hz and the peak power levels are observed around 1000 – 2000Hz. Western classical music on the other hand is described as dynamic due to the frequent changes in spectral patterns, also it has a wider frequency range with an upper limit of 18000Hz and the peak levels are seen between 2000 – 3000Hz. Opera is defined as “semi-dynamic” due to being in between TCM and western classical music, sharing its frequency range with western classical music with an upper limit of 18000Hz and peak power levels around 4000Hz. In terms of musical structure, TCM was defined as “stable” in contrary to western classical music and opera which were depicted as “versatile”. In western classical music, no particular dominant elements could be defined as dominancy is occasionally changeable and dependent on the song progressions. Vocals are considered dominant elements both in TCM and opera, in addition to percussions being considered important in TCM.

In order to identify these differences more clearly, a visual example representing three different spectrogram examples from three different music styles is given consecutively at Figure 3.1.5 below. The selected pieces were considered to distinctly reflect their correspondent music style. The first example (a) is from TCM which is named “Yar Saçların Lüle Lüle” by Semiramis Pekkan, recorded in 1972 with a length of 3 minutes 58 seconds. Next is a western classical music example (b), the overture piece from the “Magic Flute” opera written by Wolfgang Amadeuz Mozart in 1791, being 7 minutes and 14 seconds long. Finally, the last example (c) is an opera piece “Mein Herr Marquis” from the opera “Die Fledermaus” written by Johann Strauss in 1874 with a length of 5 minutes and 48 seconds.

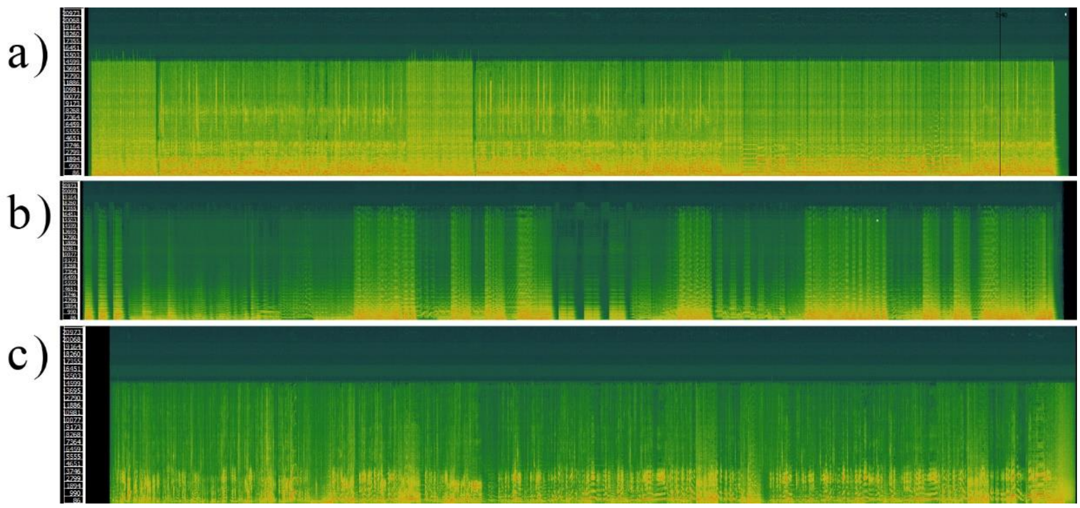


Figure 3.18. a) Spectrogram view of “Yar Saçların Lüle Lüle” by Semiramis Pekkan (1972)
b) Spectrogram view of “Overture” from “The Magic Flute” (Mozart, 1791)
c) Spectrogram view of “Mein Herr Marquis” from “Die Fledermaus” (Strauss, 1874)

Examining the three spectrogram examples yields clearer information about the differences and similarities between the music styles. In the first example (a), the frequency “border” can be distinguished, with an upper limit of 14000Hz and peak power levels between 1000 – 2000Hz. The latter examples (b) and (c) display the dynamic spectral changes over time and versatile musical structure as opposed to the static progression in TCM (a). Power spikes can be seen throughout all three examples, indicating vocal patterns in (a) and (c) and cymbal blasts in (b), however; they are much more recognizable in (b) and (c) unlike (a). Although dominant elements cannot be identified solely by inspecting the spectrograms, the presence of frequent power spikes in (a) points out the possibility of speech, furthermore, octave bands can be observed in all three, indicating the presence of musical sounds which then can be interpreted as harmonized vocals with instruments.

Different performance types require different acoustic conditions, as mentioned earlier. Barron (1993) suggested optimum reverberation times (RT) for mid frequencies should be approximately between 1,8 and 2,2 seconds for classical music, and between 1,3 and 1,8 seconds for opera depending on the type. Reverberation times for low frequencies may be 1.2 – 1.4 RT and high frequencies may be 0.8 RT (Egan, 1977). Early decay times (EDT) between 2,25 and 2,75 seconds are considered to give the best results for concert halls and optimum results were observed around 1,40 – 1,75 seconds for opera houses (Beranek, 2004). Clarity (C_{80}) values for classical music and opera are most successful between -4 dB and +4 dB, however values between 0 and +4 dB are considered slightly more successful, in addition; distinctness (D_{50}) values are known to provide the best results between 0,45 – 0,60 (Beranek, 1996).

Table 3.2. below presents the breakdown of major features for each type of music. Classical music and opera both house symphony orchestras with a large quantity of musicians. Turkish classical music, on the other hand, has a smaller orchestra commonly with 4 to 10 people.

The main distinctive quality that differentiates opera and TCM from classical music is the presence of vocals, which brings out the concern of intelligibility. The C_{80} and D_{50} parameters are directly linked with speech intelligibility, thus they are significant parameters for opera and TCM. This brings out the possibility of making assumptions for TCM based on the major features of opera, and comparing both musical styles in terms of acoustic conditions.

Table 3.2. *Major features of classical music, opera and Turkish classical music*

Quality	Classical Music	Opera	Turkish Classical Music
Orchestra	large orchestra	large orchestra	small orchestra
Instruments	strings, woodwinds, brass, percussion	strings, woodwinds, brass, percussion	reed flute, kanun, tambour, bendir
Vocals	none	soprano, alto, tenor, bass	soprano, tenor
Room shape	rectangular	horseshoe	n/a
Room size	8-11 m^3 per person	6-8 m^3 per person	n/a
RT	1,8-2,2 s	1,3-1,8 s	0,8-1,1 s
EDT	2,25-2,75 s	1,40-1,75 s	n/a
C_{80}	-4 dB < C_{80} < +4 dB	-4 dB < C_{80} < +4 dB	0 dB < C_{80} < +4 dB
D_{50}	0,45-0,60	0,45-0,60	n/a
BR	1,0-1,4	1,0-1,4	1,1-1,2

A successful room depends on whether or not the whole audience receives the sound coming from the source in equal satisfaction. This depends on the room size, shape, stage design and acoustic parameters. If the room itself cannot provide natural conditions where additional amplification is needed for the sound source, the room may easily be accepted as unsuccessful. Regarding size, opera has a relatively larger orchestra, which provide higher sound pressure levels, making it easier to fill the room and reach the audience. TCM, however, has a smaller orchestra, thus needing amplification in most cases. This may bring out the question of the room size and shape, which affect the RT and EDT values that are required for TCM where no amplification is necessary for successful results.

Instruments that are used in opera are the same as a symphony orchestra, where various instruments from four instrument groups have an overall wide range of frequency. TCM has a limited number of traditional Turkish instruments, with a limited range in terms of frequency, in response to opera. The reed flute is more dominant in mid-to-high frequencies, where the kanun, tambour and bendir have a low frequency range. Hence, it can be assumed that the management of low frequencies are essential for TCM and the BR parameter is directly linked to this matter. Additionally, the higher pitched vocals and the reed flute also need to avoid masking from low frequencies, which brings out the TR parameter in question.

The discussions that were made above can be summarized as:

- Turkish music and opera both have vocals as their distinctive feature. C_{80} and D_{50} parameters play a large role on the acoustic conditions for both.
- RT and EDT values are significant parameters to determine room shapes and sizes for TCM, where amplification is not needed.
- While opera has a wide frequency range due to the variety of different instrument groups, TCM is more predominantly based in the low-to-mid frequencies. The BR parameter is directly linked to this matter, thus becomes a significant factor regarding the acoustic conditions of TCM.
- As a result of soprano and tenor voices being more common in TCM, high frequencies require to be clear and distinct. This depends on the TR parameter and needs to be dealt with for optimum results.

Previous literature points out that although some studies have been done to analyze the acoustic parameters for existing spaces where Turkish music was performed during the Ottoman period, no studies were found in the scope of determining optimum acoustic conditions for TCM.

A study done by Gülçin Konuk (2010) inspects four case studies of closed spaces in Ottoman palaces, typically music chambers in their master's thesis, and puts forth several suggestions for future studies for acoustic conditions of TCM. Konuk recommends that until further studies have been made to determine optimum conditions, parameters for chamber music could be taken as a reference when examining similar traditional spaces. However, Konuk's analyses of the four spaces yield results that are far from optimum conditions, especially in terms of C_{80} values. Konuk suggests that a new C_{80} value should be determined for TCM.

Özçevik & Yüksel Can (2015) have also proposed a method for the evaluation of rooms used for performing Turkish music. Three different rooms were examined in terms of room acoustic parameters and objective parameters were correlated with subjective parameters. Fırat & Yüksel Can (2015) have made a study on the acoustic properties of Mevlevi lodges (Mevlevihane) where TCM used to be performed. In both of these studies, the optimum parameters for chamber music were considered as applicable for TCM, since there was no information available regarding actual optimum values for TCM.

The distinguishing factor of this thesis that differentiates from previous studies regarding Turkish music is that while previous studies focused on the evaluation of existing spaces, this study mainly focuses on creating a guideline to design a room from scratch that is able to meet the conditions for TCM.

This study gives an example on the lack of acoustic design for Turkish music and points out that spaces for music were not designed and calculated deliberately or intentionally, and were built without acoustic concerns in mind. This becomes an issue for both performers and listeners of Turkish music. Since no building was designed to fit TCM conditions (even though some may have coincidentally), Turkish music was never given the opportunity to fully transfer its musical characteristics in its ideal forms. This thesis is considered to be a guideline and a starting point for future studies in the aim of achieving better conditions for TCM and improve the quality of Turkish music, perhaps even bring back the art form as it was commonly appreciated and acknowledged as it used to be.

CHAPTER 4

MATERIALS AND METHODOLOGY

In this chapter, the materials and method of the study is to be presented. The first section talks about the materials used for the study. Anechoic recordings of five different TCM pieces were provided by the courtesy of previous researchers who were involved in a TUBİTAK project that had to be postponed due to limited budget and time. These recordings are then transferred into Odeon room acoustics software to be auralised in three different performance spaces with different RT, EDT, C_{80}, D_{50}, BR and TR values.

Carrying on, further experiments are conveyed in the aim of obtaining suitable parameters for TCM. A box shaped room is modelled in Odeon and the conditions of an anechoic room are calibrated into the model. Next, the objective acoustic parameters of the room are adjusted by changing the reflective materials of the room. Auralisations are made and listened along with each adjustment, and better conditions are created with each step. The conditions are decided by deriving from current information on classical music, opera and chamber music, along with assumptions that were developed from the analyses in Chapter 3.

Afterwards, the auralisations made in the box room are presented to a test group of experts to be listened. The listeners are asked to fill out an evaluation form about the different conditions for each song. The evaluation consists of a semantic differential scale test of the following parameters: clarity, warmth, richness, intimacy and overall satisfaction. The subjective results of the test are used to determine possible optimum acoustic conditions and parameters for TCM.

The outputs derived from the listening test are then applied to the three performance spaces in hopes of enhancing the acoustic quality and bringing it closer to an optimum.

A second listening test is conducted to the same test group where the existent conditions of the performance spaces and the improved conditions are asked to be compared. The subjective results of the questionnaire are then correlated with the objective parameters of the three spaces. Results are discussed in the fifth chapter.

4.1. Anechoic Room Recordings

This study aims to find out suitable acoustic parameter values for TCM, hence the listeners should be able to hear examples of Turkish music as if they were in the room themselves in order to assess the acoustic quality of said spaces. The first step on doing this is making an anechoic recording of a TCM performance. Since this study has had its limitations, the author was unable to create their own recordings. However, recordings from a previously done research by Özçevik & Yüksel Can (2015) were used for the study, with the authors' permissions. The recordings were taken in the anechoic chamber which belongs to TUBİTAK National Metrology Institute, with the conduction of Prof. Dr. Ruhi Ayangil and an orchestra of six instruments. A total of five recordings and the instruments that were used in this study are as follows:

- Sample 1: Female vocal, male vocal, tambour, kanun
- Sample 2: Reed flute, bendir, tambout (instrumental)
- Sample 3: Single reed flute partition in hicaz makam
- Sample 4: Female vocal, male vocal, bendir, reed flute, kanun
- Sample 5: Female vocal, male vocal, bendir, tambour, kanun

The examples mentioned above are then taken into Odeon room acoustics software and auralisations are made using the convolution method. Detailed information on the performance spaces for the auralisations are presented in the next section.

4.2. Modelling of the Performance Spaces

Obtaining the anechoic recordings is the initial action, followed by creating auralisations for the recordings. A computer model created in the 3D environment is required for the auralisation process. For this study, three different performance spaces with different aspects were modelled. The spaces were selected randomly to reflect different behaviors of sound, with each space having a different size.

The first performance space is Ankara Opera House, which is currently being used for operas, ballets and dramas. It is a shoebox shaped hall that has a seating capacity of 698 with a volume of 5430 m^3.

The model used for Ankara Opera House was provided by the courtesy of Gonca Örün, who did a study on the acoustic evaluation of early republican buildings in Ankara (Örün, 2011). Figure 4.1. shows an axonometric view of the model, where a plan view can be found in Figure 4.2. and a section in Figure 4.3.

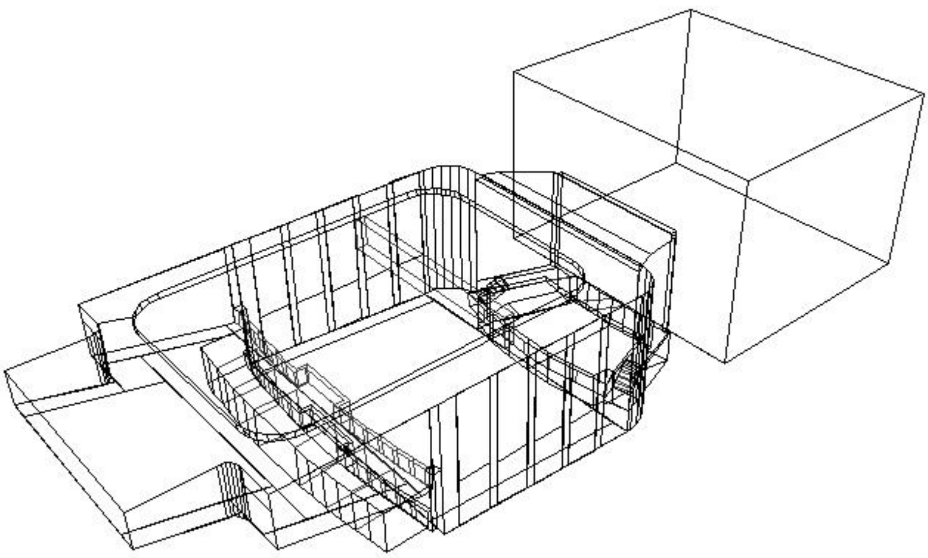


Figure 4.1. Axonometric view of Ankara Opera House

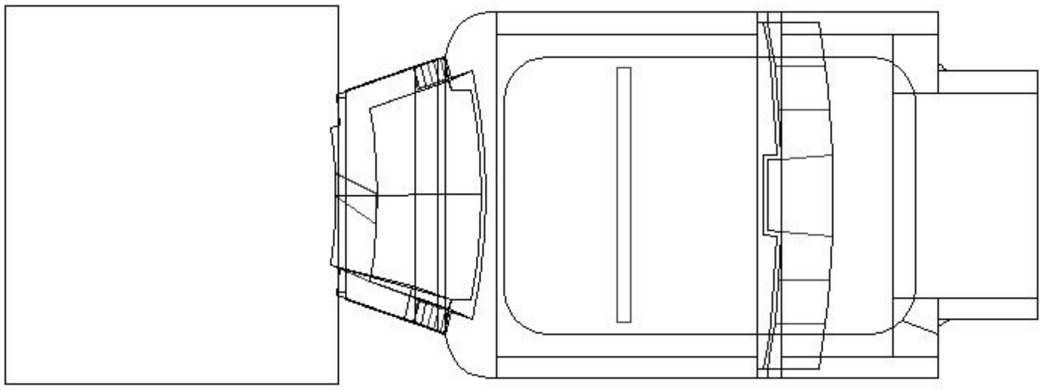


Figure 4.2. Plan view of Ankara Opera House

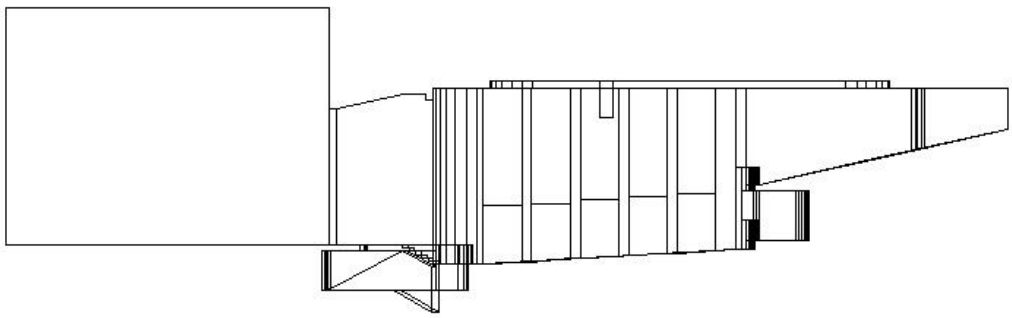


Figure 4.3. Section view of Ankara Opera House

The next two performance spaces are both conference halls that are used for multiple purposes like music and speech. The first one is the conference hall of Eskişehir Chamber of Certified Public Accountants (ESMMMO) which is fan shaped and houses an audience of 264 people, with a volume of 3575 m^3. Figures 4.4., 4.5. and 4.6. subsequently show an axonometric, plan and section view of the conference hall.

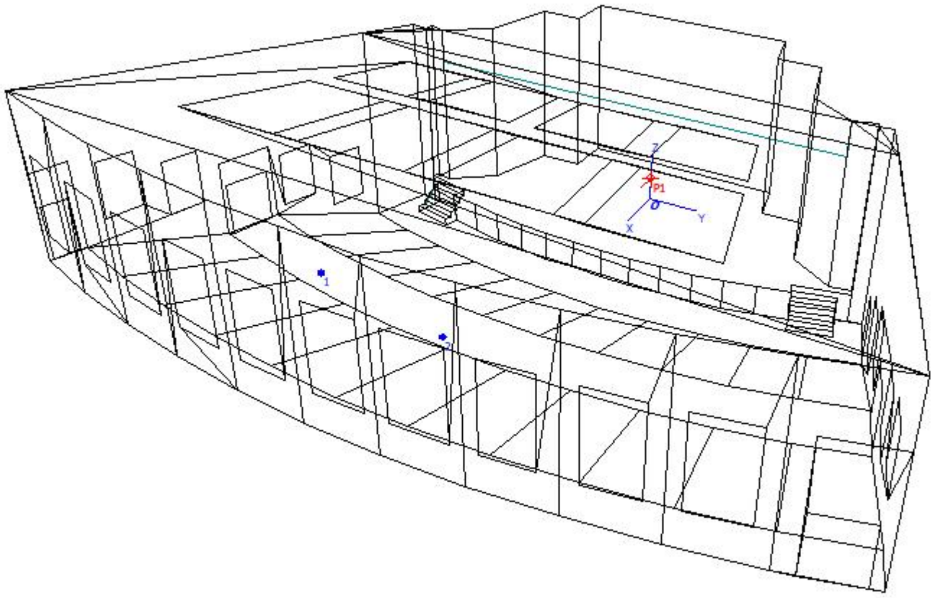


Figure 4.4. Axonometric view of ESMMMO conference hall

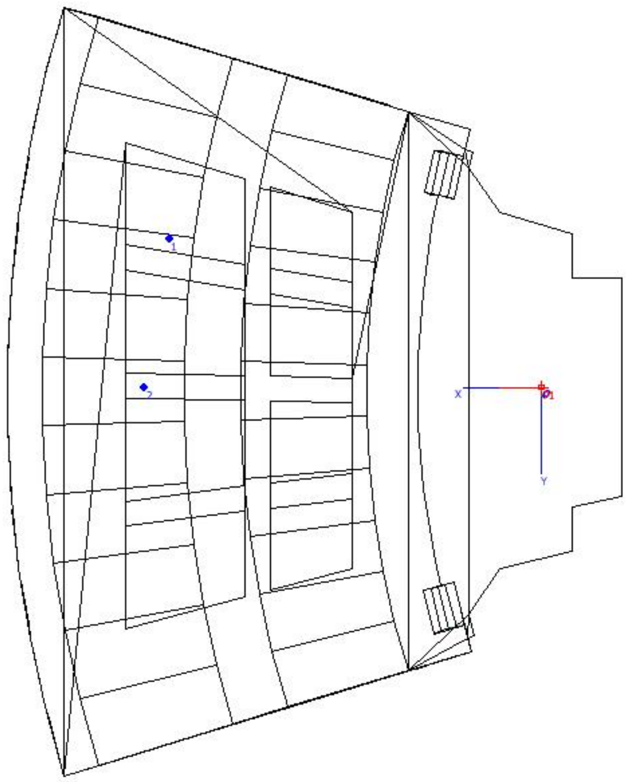


Figure 4.5. Plan view of ESMMMO conference hall

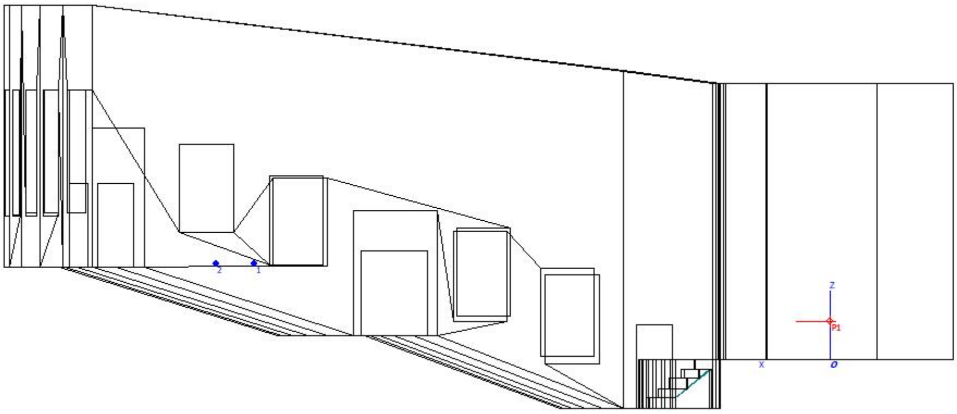


Figure 4.6. Section view of ESMMMO conference hall

The final model that was used for this study is of a conference hall of Combatant Air Force and Air Missile Defense Command which is located in Eskişehir.

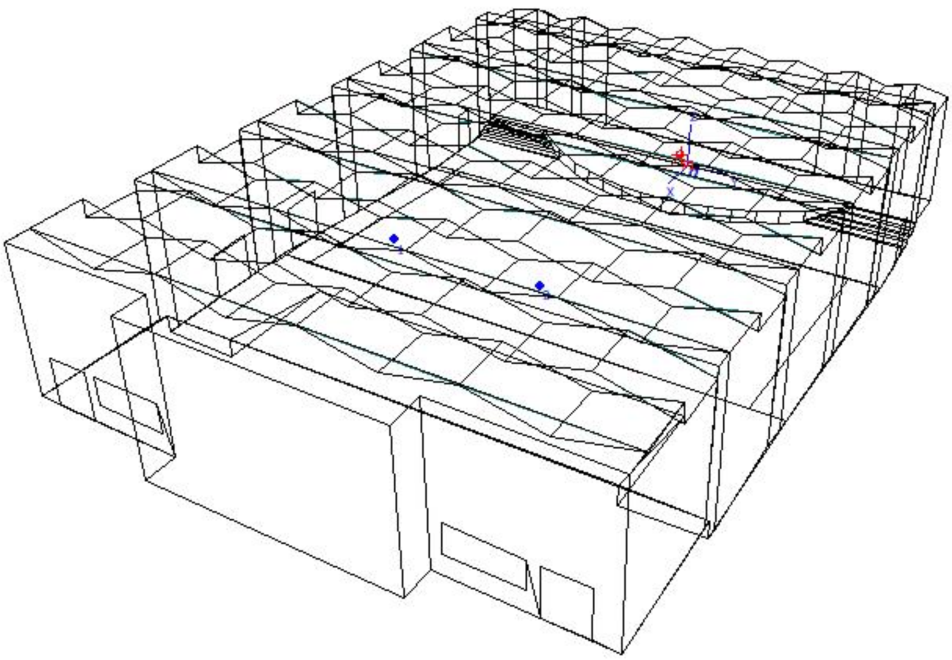


Figure 4.7. Axonometric view of Air Force conference hall

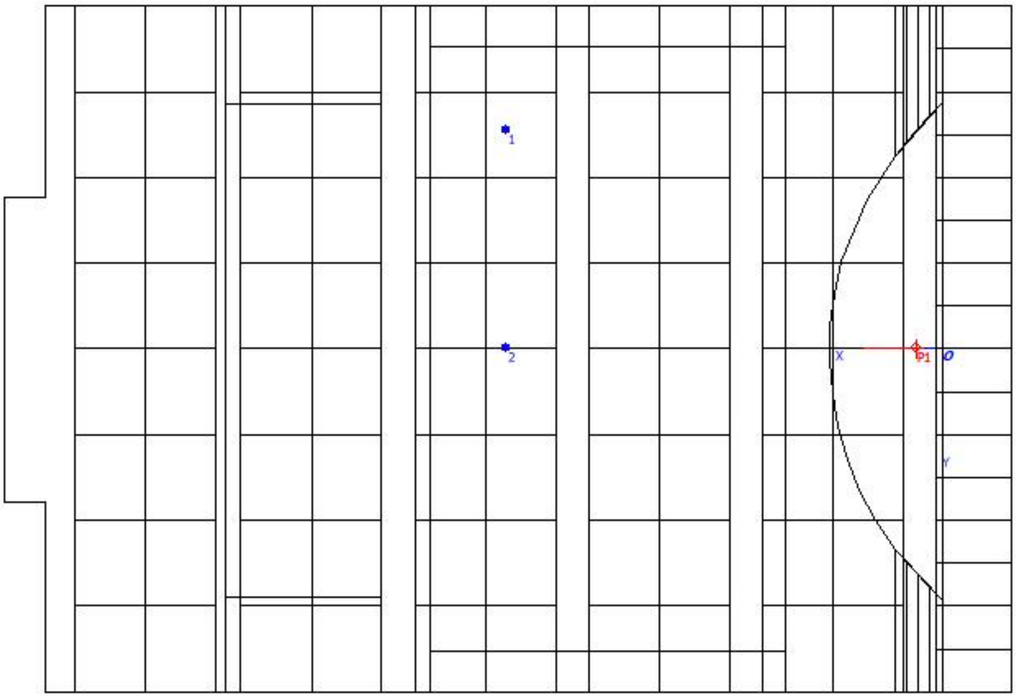


Figure 4.8. Plan view of Air Force conference hall

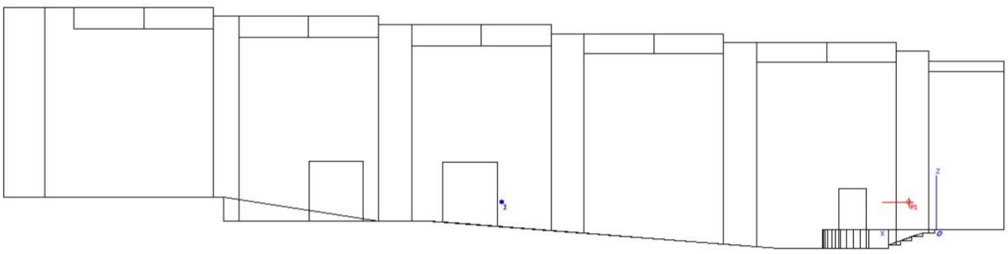


Figure 4.9. Section view of Air Force conference hall

The conference hall is box shaped and is mainly used for speech, with a seating number of 391 and a volume of 2345 m^3. Axonometric, plan and section views are demonstrated above in Figures 4.7., 4.8. and 4.9.

The three performance spaces are modelled using 3D modelling software which were uploaded into Odeon room acoustics software afterwards. In order to make acoustic calculations and auralisations in Odeon, materials need to be assigned in each surface of a room. The materials reflect the absorption coefficients of real materials, depending on their type such as wood or carpet. Below in Tables 4.1., 4.2. and 4.3. are all of the materials and their acoustic properties that were used in Odeon.

Table 4.1. *Material properties of surfaces in Ankara Opera House*

Surface Type	Material	Absorption Coefficient							
		63 Hz	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
Walls	Wood cladding on concrete	0,42	0,42	0,21	0,10	0,08	0,06	0,06	0,06
Ceiling	Wood cladding on concrete with air gap between	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
Floor	Parquet on concrete floor	0,20	0,15	0,10	0,10	0,10	0,05	0,10	0,10
Audience	Medium leather upholstered audience seats	0,62	0,62	0,72	0,80	,083	0,84	0,85	0,85
Stage walls	Large smooth plastered painted hard concrete	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
Stage curtain	Heavy velvet curtain	0,59	0,59	0,59	0,81	0,64	0,26	0,17	0,17
Stage floor	Parquet on concrete floor with air gap behind	0,4	0,4	0,3	0,2	0,17	0,15	0,10	0,10
Stage ceiling	Concrete surface with steel catwalks, hangings etc.	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
Orchestra floor	Parquet on concrete floor, orchestra with instruments	0,27	0,27	0,53	0,67	0,93	0,87	0,80	0,80
Orchestra walls	Plywood cladding on walls	0,30	0,30	0,20	0,15	0,13	0,10	0,08	0,08
Doors	Heavily quilted leather on heavy wooden door	0,14	0,14	0,10	0, 06	0,08	0,10	0,10	0,10
Curtains (walls)	Heavy velvet curtain	0,14	0,14	0,35	0,55	0,72	0,70	0,65	0,65
Light mass	Plastered concrete surface with lighting instruments	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02

Table 4.2. *Material properties of surfaces in ESMMMO conference hall*

Surface Type	**Material**	**Absorption Coefficient**							
		63 Hz	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
Walls	Plywood panel on concrete	0,42	0,42	0,21	0,10	0,08	0,06	0,06	0,06
Wall panels	Perforated gypsumboard	0,18	0,18	0,32	0,71	0,99	0,50	0,29	0,29
Ceiling	Wood cladding on concrete with air gap between	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
Ceiling panels	Plywood panel on concrete	0,42	0,42	0,21	0,10	0,08	0,06	0,06	0,06
Stage ceiling	Concrete surface with steel catwalks, hangings etc.	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
Stage curtain	Light velvet curtain	0,05	0,05	0,10	0,10	0,20	0,20	0,30	0,30
Floor	Carpet on concrete	0,09	0,09	0,08	0,21	0,26	0,27	0,37	0,37
Audience	Medium leather upholstered audience seats	0,62	0,62	0,72	0,80	,083	0,84	0,85	0,85
Stage floor	Parquet on concrete floor, orchestra with instruments	0,27	0,27	0,53	0,67	0,93	0,87	0,80	0,80
Doors	Solid wooden door	0,14	0,14	0,10	0,06	0,08	0,10	0,10	0,10

Table 4.3. *Material properties of surfaces in Air Force conference hall*

Surface Type	**Material**	**Absorption Coefficient**							
		63 Hz	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
Walls	Plywood panel on concrete	0,42	0,42	0,21	0,10	0,08	0,06	0,06	0,06
Wall panels	16-22mm wood facing	0,25	0,25	0,15	0,10	0,09	0,08	0,07	0,07
Ceiling	Wood cladding on concrete with air gap between	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
Ceiling panels	Plywood panel on concrete	0,42	0,42	0,21	0,10	0,08	0,06	0,06	0,06
Floor	Carpet on concrete	0,09	0,09	0,08	0,21	0,26	0,27	0,37	0,37

Table 4.3. *(continued)*

Audience	Medium leather upholstered audience seats	0,62	0,62	0,72	0,80	,083	0,84	0,85	0,85
Stage floor	Parquet on concrete floor, orchestra with instruments	0,27	0,27	0,53	0,67	0,93	0,87	0,80	0,80
Doors	Solid wooden door	0,14	0,14	0,10	0,06	0,08	0,10	0,10	0,10
Glass	Single pane of glass	0,08	0,08	0,04	0,03	0,03	0,02	0,02	0,02

4.3. Listening Test and Evaluation Sheet

The auralisations of the anechoic recordings in the three performance spaces that were mentioned in the previous section are used for a listening test. Since the objective parameters of a room is not enough to fully comprehend the optimum conditions, a correlation between objective and subjective parameters is required, which can only be achieved by the subjective opinions of the listeners.

A semantic differential test is conducted to the listeners in the aim of creating a relationship between objective and subjective parameters. The objective parameters that were focused on in this study are reverberation time (RT), early decay time (EDT), clarity (C_{80}), distinctness (D_{50}), bass ratio (BR) and treble ratio (TR). The parameters were chosen accordingly to fully represent the distinct characteristics of TCM in the most effective way.

The test is conducted to experienced music listeners, which are students and teachers of the Turkish music department of Anadolu University Conservatory, Turkish music performers, and music therapists. A total of 55 listeners have taken the listening test. The listeners used noise cancelling headphones for the test.

The test consists of two stages. The first stage consists of listening to the auralisations that were made in the box room model. The listeners are asked to choose the most appealing alternative out of four different references of each TCM piece according to musical quality. Afterwards, the listeners are presented with 10 different alternatives for a single TCM song, and are asked to select four alternatives which they find most pleasing. Finally, the listeners are asked to fill out two evaluation sheets, one for the alternative that they have appreciated the most, and one for the least.

The second stage involves listening to the existent and improved alternatives for each TCM piece that were auralised in the three performance spaces. The listeners are then asked to fill the aforementioned evaluation sheet for both instances, and to choose between the two instances for different parameter preferences. A blank example of the evaluation sheet can be found in the Appendices section of this thesis.

CHAPTER 5

RESULTS AND DISCUSSION

This chapter consists of a detailed layout of findings gathered from the study. Objective acoustic parameters that were gathered from Odeon room acoustics software are presented along with the results of the listening tests that were conducted.

5.1. Auralisations of Three Performance Spaces

The selected three performance spaces are modelled in 3D modelling software before being imported into Odeon. Afterwards, materials are assigned to the surfaces in the models to match the appropriate absorption coefficients, as mentioned before in Chapter 4. Later, a sound source and a receiver is defined in order to make acoustic calculations and auralisations. In this study, a single point receiver and a grid has been defined for each performance space. The single point receiver is placed directly in front of the source to eliminate complications that may be caused by LF_{80} and LG_{80}. The receiver is 16 meters away from the source in each space, being approximately in the middle of the room. Acoustic parameters that were calculated in Odeon are shown below in Table 5.1.

Table 5.1. *EDT, RT, C_{80}, D_{50}, BR and TR values of performance spaces*

Performance Space	***EDT***		***T_{30}***		***C_{80}***		***D_{50}***		***BR***	***TR***
	500 Hz	**1000 Hz**	**500 Hz**	**1000 Hz**	**500 Hz**	**1000 Hz**	**500 Hz**	**1000 Hz**		
Ankara Opera House	0,81	0,74	1,24	1,28	5,8	6,4	0,62	0,66	0,98	1,00
Air Force Conference Hall	1,43	1,14	1,40	1,42	2,3	3,4	0,44	0,51	1,05	0,91
ESMMMO Conference Hall	1,33	1,23	0,98	0,88	2,4	3,7	0,50	0,58	1,08	1,03

Early decay times are the lowest in Ankara Opera House with a value of 0,81 seconds in 500 Hz and 0,74 in 1000 Hz. The best results are observed when EDT values are 1.1 times or higher than RT values in rooms. Even though RT values seem to be plausible for TCM, in this case, EDT values are considerably low compared to RT values. This is caused by the characteristics of TCM, which is usually performed with 4 to 10 instruments. An orchestra like this is too small for a performance space as big as Ankara Opera House. As for C_{80}, again, the values exceed the recommended interval between +4 and -4, meaning that the sound produced is no longer clear, but instead muddy. The same case is also applicable for D_{50}, which is directly related to C_{80}. However, the bass ratio BR and treble ratio TR do not seem to be that poor, even though a BR value higher than 1,0 is usually recommended.

The conference hall of Combatant Air Force and Air Missile Defense Command has the highest EDT and RT values out of the three selected performance spaces. Although, the RT values are very close to EDT values, which may cause problems regarding the subjective parameters of liveness, clarity and reverberance. C_{80} and D_{50} values are believed to be in a reasonable area. This time, the BR is higher than 1,0 which complements the warmth parameter in performance spaces.

The Eskişehir Chamber of Certified Public Accountants conference hall seems to yield the most successful results in the relationship between EDT and RT values. However, the RT value is considered to be too low for music, which is usually between 1,8 - 2,2 for classical music, 1,3 – 1,8 for opera and 1,1 – 1,6 for chamber music, which is currently being referred to for TCM. The values for C_{80} and D_{50} are almost the same as the Air Force conference hall, with slightly better values for BR and TR.

The objective acoustic parameters for the selected performance spaces present different strengths and weaknesses for each space. While the Ankara Opera House and Air Force conference hall have better reverberation times for TCM, the ESMMMO conference hall seems to have an advantage regarding warmth and clarity.

5.2. Anechoic Chamber Auralisations

A virtual box room is modelled after the auralisations of the selected three rooms. This box is adjusted to have conditions close to the anechoic room in TUBİTAK National Metrology Institute. Its dimensions are 8,89 x 3,99 x 3,53 meters. The walls of the anechoic room are covered with Ferrite and carbon-impregnated hybrid sponges. In Odeon, a custom material is made to imitate the absorption coefficients of the room. Afterwards, the material absorption coefficients were altered into four different reference points and reconstructed auralisations were made in order to assess the acoustic quality of TCM recordings.

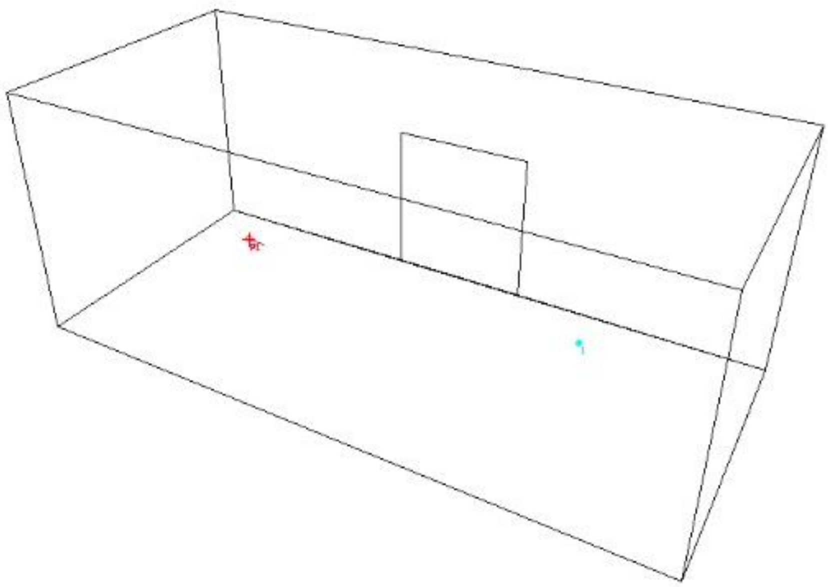


Figure 5.1. Axonometric view of the anechoic box room

References 1 through 4 were constructed in order to construct rooms that have distinguishable RT values, with Reference 1 having the lowest RT and Reference 4 having the highest. As the RT values were modified, other parameters have changed due to the changing room conditions, as well.

Table 5.2. *Absorption coefficients that were assigned in the box room references*

Reference Number	Absorption Coefficient							
	63 Hz	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
Reference 1	0,93	0,92	0,93	0,95	0,91	0,92	0,91	0,90
Reference 2	0,49	0,48	0,48	0,45	0,43	0,42	0,42	0,40
Reference 3	0,12	0,13	0,12	0,10	0,11	0,10	0,10	0,10
Reference 4	0,05	0,05	0,05	0,05	0,03	0,03	0,03	0,03

Table 5.2. presents the absorption coefficients of the four references in the box room model. In Reference 1, material absorption coefficients are kept as close to 1,0 as possible in order to reflect the existing conditions of the anechoic room. The material absorption coefficients in the following references are lowered in each step, in the aim of achieving four different conditions that are clearly distinguishable from each other.

Table 5.3. *EDT, RT, C_{80}, D_{50}, BR and TR values of the box room references*

Reference Number	***EDT***		***T_{30}***		***C_{80}***		***D_{50}***		***BR***	***TR***
	500 Hz	**1000 Hz**	**500 Hz**	**1000 Hz**	**500 Hz**	**1000 Hz**	**500 Hz**	**1000 Hz**		
Reference 1	0,04	0,04	0,04	0,05	91,10	77,50	1,00	1,00	1,3	1,00
Reference 2	0,21	0,21	0,25	0,26	20,90	20,40	0,96	0,96	0,94	1,05
Reference 3	0,93	0,82	0,93	0,82	3,20	3,90	0,50	0,53	0,84	0,98
Reference 4	1,54	2,03	1,49	1,93	-0,20	-1,90	0,34	0,27	0,85	0,98

The objective parameters that were calculated for each reference are presented in Table 5.3. above. It can be seen that each reference has different parameters in EDT, RT, C_{80} and D_{50} values. Considering that previous studies have recognized chamber music conditions acceptable for TCM, Reference 3 was taken as a starting point due to having similar conditions with chamber music.

Taking Reference 3 into account, 10 different alternative room conditions were constructed using Odeon software. In each alternative, material absorption coefficients were modified in the aim of achieving different parameters. The purpose of creating 10 alternatives was to examine different scenarios where some parameters were kept similar and others were changed, such as RT values being close to each other but BR values being different, in order to evaluate the objective parameters and their subjective equivalents more easily. Table 5.4. shows the material absorption coefficients in each octave band that were assigned in each alternative scenario.

Table 5.4. *Absorption coefficients that were assigned in the box room alternatives*

Alternative Number	**Absorption Coefficient**							
	63 Hz	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
Alternative 1	0,08	0,07	0,08	0,10	0,11	0,10	0,10	0,10
Alternative 2	0,12	0,13	0,12	0,20	0,20	0,30	0,30	0,30
Alternative 3	0,05	0,05	0,05	0,10	0,15	0,15	0,13	0,13
Alternative 4	0,06	0,05	0,06	0,08	0,09	0,08	0,08	0,08
Alternative 5	0,04	0,03	0,04	0,06	0,07	0,06	0,06	0,06
Alternative 6	0,06	0,06	0,06	0,06	0,07	0,06	0,06	0,06
Alternative 7	0,03	0,02	0,03	0,04	0,05	0,04	0,04	0,04
Alternative 8	0,05	0,04	0,05	0,04	0,05	0,04	0,04	0,04
Alternative 9	0,03	0,02	0,03	0,06	0,07	0,03	0,03	0,03
Alternative 10	0,04	0,04	0,04	0,06	0,06	0,04	0,04	0,04

The objective parameters that were found after room calculations in Odeon software are displayed in Table 5.5. below. As mentioned earlier, some parameters were kept the same while others were modified between various alternatives. For instance, in Alternatives 7 and 8, the BR parameter was altered while the remaining objective parameters were kept unchanged. This was made to identify the effect of the change in certain subjective parameters and to determine the better alternative.

Table 5.5. *EDT, RT, C_{80}, D_{50}, BR and TR values of the box room alternatives*

Alternative Number	***EDT***		***T_{30}***		***C_{80}***		***D_{50}***		***BR***	***TR***
	500 Hz	**1000 Hz**	**500 Hz**	**1000 Hz**	**500 Hz**	**1000 Hz**	**500 Hz**	**1000 Hz**		
Alternative 1	0,95	0,84	0,91	0,83	3,20	3,80	0,51	0,54	1,28	0,95
Alternative 2	0,48	0,55	0,51	0,54	8,50	8,60	0,74	0,74	1,44	0,60
Alternative 3	0,95	0,66	0,91	0,64	3,20	6,00	0,51	0,64	1,89	0,80
Alternative 4	1,09	1,03	1,09	0,96	1,90	2,60	0,45	0,48	1,33	0,94
Alternative 5	1,40	1,25	1,31	1,17	0,50	1,30	0,98	0,42	1,44	0,93
Alternative 6	1,40	1,25	1,31	1,17	0,50	1,30	0,38	0,42	1,10	0,93
Alternative 7	1,74	1,56	1,65	1,46	-1,10	-1,10	0,30	0,35	1,36	0,93
Alternative 8	1,74	1,56	1,65	1,46	-1,10	-0,10	0,30	0,35	1,01	0,93
Alternative 9	1,40	1,25	1,31	1,17	0,50	1,30	0,38	0,42	1,71	1,33
Alternative 10	1,40	1,34	1,31	1,30	0,50	0,60	0,38	0,38	1,27	1,12

Regarding EDT and RT values, it can be said that Alternative 2 has adjacent conditions to rooms for speech, while Alternatives 1, 3 and 4 have similar conditions to chamber music. Alternatives 5 to 10 are considered to have close conditions to opera, however, Alternatives 7 and 8 have higher RT and EDT values compared to Alternatives 5, 6, 9 and 10. These 10 scenarios are used in a listening test which is explained in the following section of this study.

5.3. Results of the First Listening Test

The auralisations that were made in the box room were used for a listening test. The test is conducted to a total of 55 people. Three of the output data were unworkable, hence, a total of 52 results were examined for this study.

For the initial part of the test, auralisations that were made in References 1, 2, 3 and 4, which were discussed in the previous section, are used. Listeners are given four different alternatives (one of each reference condition) of each TCM piece along with the original anechoic recordings, and are asked to pick the most desirable alternative out of the four alternatives. The anechoic recordings are given solely as a reference point in order for the listeners to be able to distinguish the differences between each reference more efficiently, and are not an option to be selected. The outputs for each TCM piece are shown below in Figures 5.2 to 5.6.

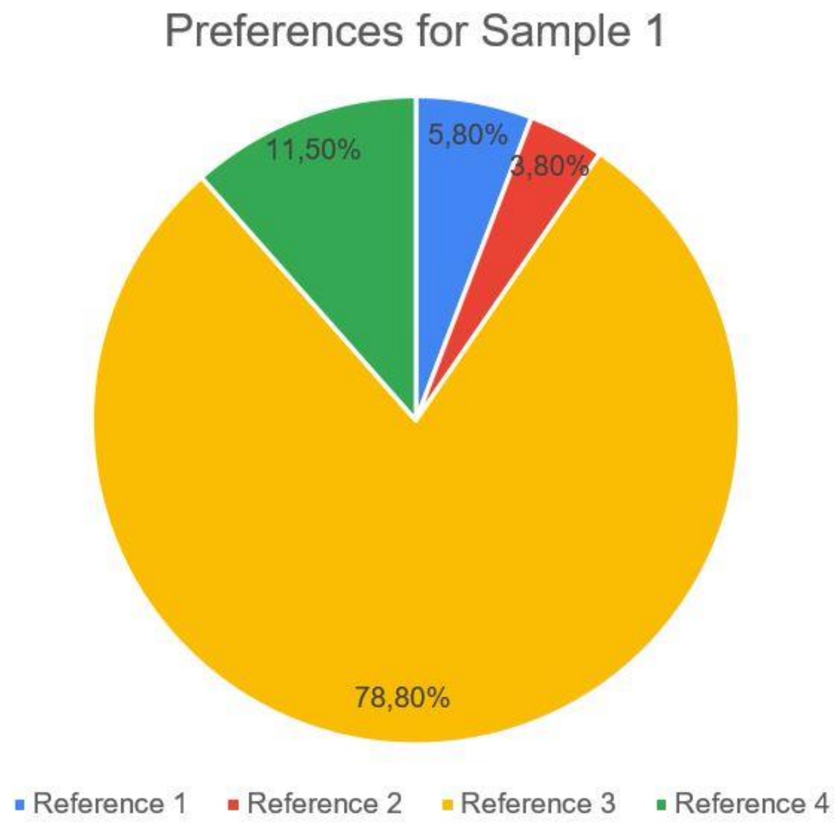


Figure 5.2. Listening test results for Sample 1

Figure 5.2. demonstrates the preference results for song Sample 1. The song comprises of a female and male vocal, a tambour and a kanun. The male vocal is present only within a small part and accompanies the female singer, who is present throughout the song. Out of the 52 candidates, 41 people have chosen Reference 3 as the most

desirable one, which is 78,8% in percentage. While 6 candidates have selected Reference 2, References 1 and 4 were selected by 3 and 2 people, respectively.

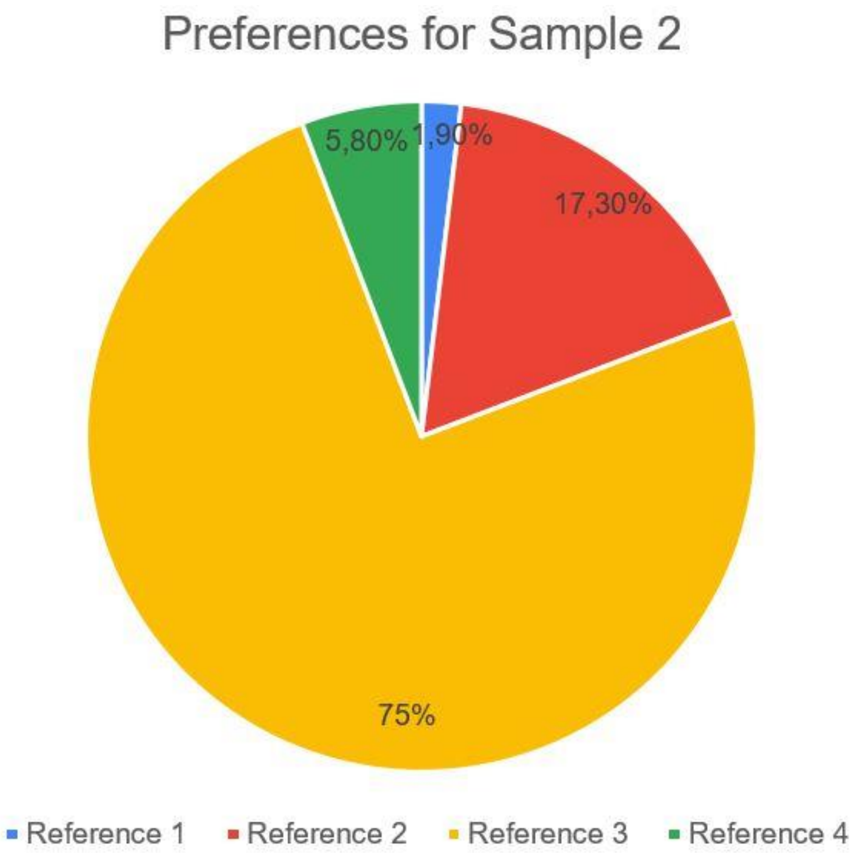


Figure 5.3. Listening test results for Sample 2

The next sample is an instrumental piece consisting of a reed flute (ney), a bendir and a tambour. The reed flute is the leading element in this piece. As seen above in Figure 5.3., 75% of the candidates have chosen Reference 3, with a count of 39, while 9 candidates selected Reference 2 with a percentage of 17,3%. References 1 and 4 remain the least preferable for this song as well.

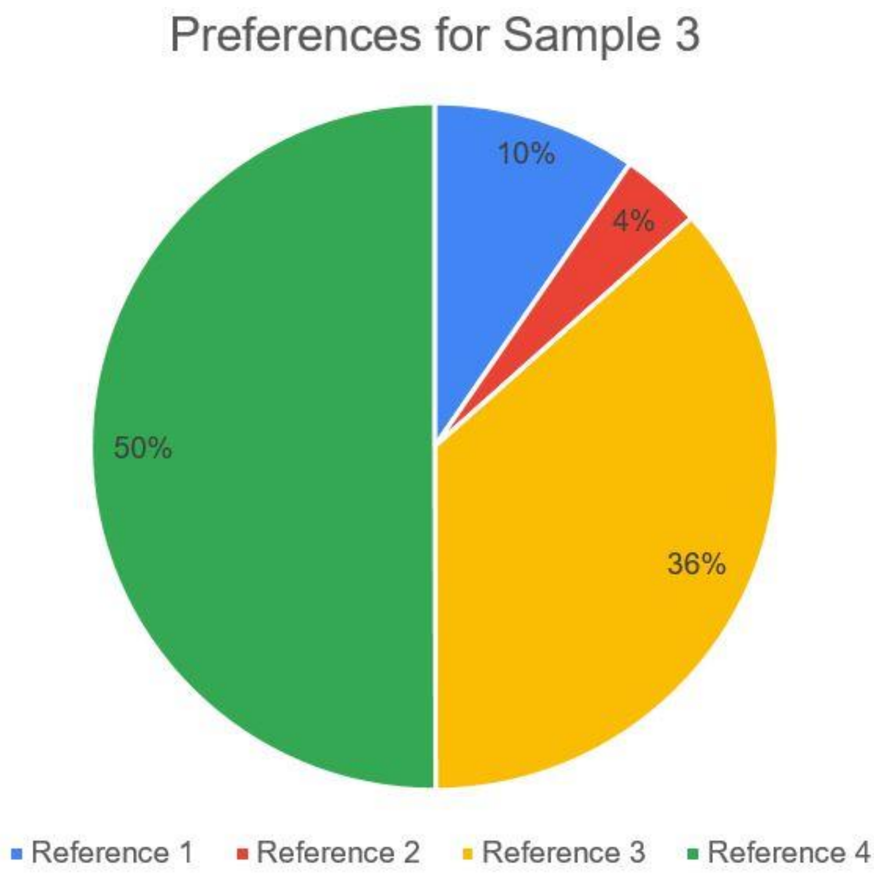


Figure 5.4. Listening test results for Sample 3

The third piece is a partition (taksim) which is a style in Turkish music where a single instrument is played without rhythm. In this case, the instrument is the reed flute. Presented in Figure 5.4., half of the candidates have chosen Reference 4 and Reference 3 was selected by 36% with a count of 19.

Figure 5.5. shows the preferences that were made for Sample 4, which is a TCM song in the Segah makam, and consists of a male and female singer, a bendir, a reed flute and a kanun. A majority of the listeners have chosen Reference 3 as the most preferable alternative, with a percentage of 75%. A total of 7 people have chosen Reference 2 and References 1 and 4 were selected by 3 people each.

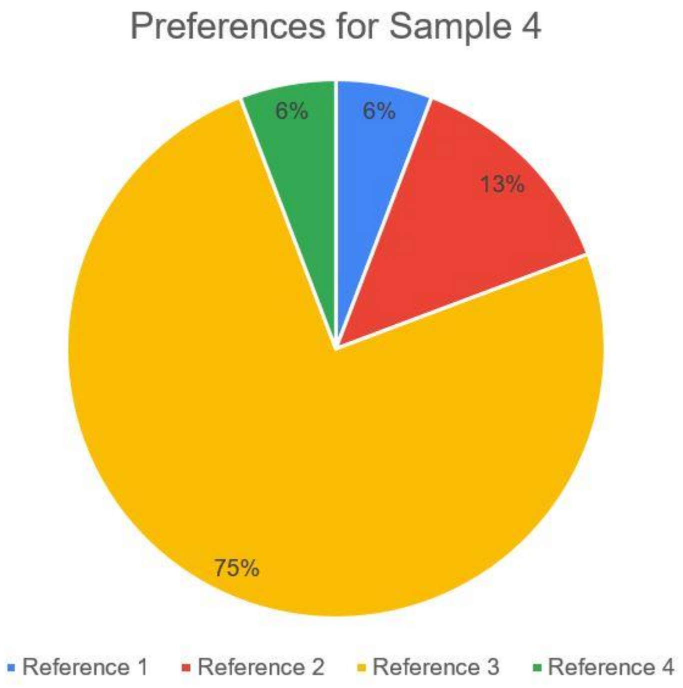


Figure 5.5. Listening test results for Sample 4

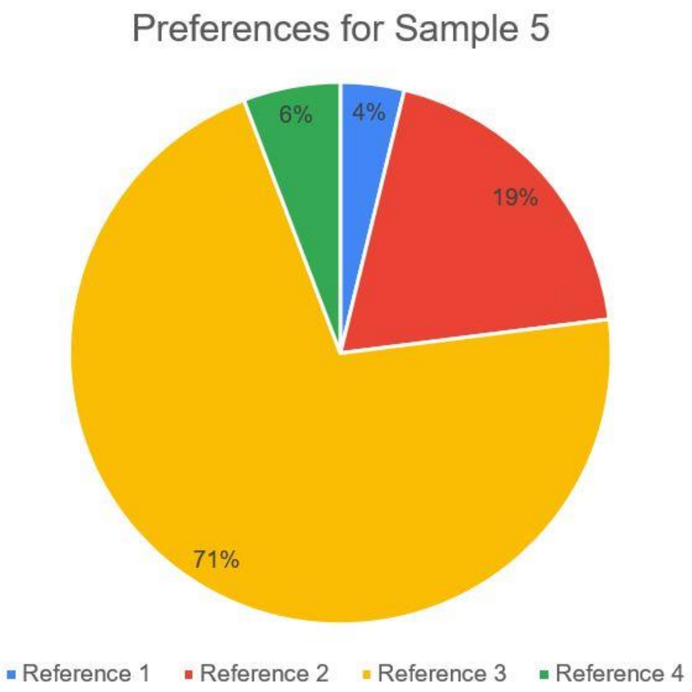


Figure 5.6. Listening test results for Sample 5

The final TCM sample that was presented to the listeners is a song which is played in the Muhayyer Kürdi makam. This song comprises a bendir, a kanun and a tambour, along with male and female singers. Once more, Reference 3 is chosen by the majority of the candidates with a percentage of 71% and a count of 37. Reference 2 was chosen by 10 people whereas Reference 1 has a pick rate of 2, and Reference 4 having been chosen by 3 candidates.

The first part of the listening test is essential on account of being a reference point towards the second part. Reference 3 has been the most preferable alternative within four different room scenarios. The only exception is in Sample 3 where a single reed flute is played, in which Reference 4 was selected by 26 people while Reference 3 was chosen by 19. This may be due to the fact that a single instrument might sound better with a higher reverberation time, otherwise the sound might not be sufficient enough to satisfy a listener. However, Reference 3 may nevertheless be considered as a succeeding condition in this scenario, which points out that the parameters of Reference 3 might be suitable for Turkish music. In the previous section, it was mentioned that while making the box room auralisations, Reference 3 was chosen as a starting point and was used for making Attempts 1 to 10. The listening test results have shown that this approach was accurate and can be supported.

The second part of the listening test revolves around the 10 attempts which were made by taking Reference 3 and having slight changes done with each attempt. In this case, Sample 4 was used as a single song for a more controlled experiment. A total of 10 auralisations were made, one for each alternative condition. Listeners are asked to choose four alternatives of which they find the most pleasing out of the ten.

Figure 5.7. demonstrates the total count of preferences made by the listeners when asked to choose four alternatives for Sample 4. Alternatives 5 and 6 have been popular choices being chosen by 38 and 43 people out of 52, and Alternatives 9 and 10 have also been chosen by the majority of listeners, both with a count of 29. Alternative 1 has been the least preferable, with the lowest reverberation time value, followed by

Alternatives 7 and 8, which have the highest reverberation times out of the ten. Alternatives 2, 3 and 4 have slightly higher reverberation times than Alternative 1, however; they were not as preferable compared to Alternatives 5, 6, 9 and 10, which are considered to possibly have close to optimum conditions for TCM.

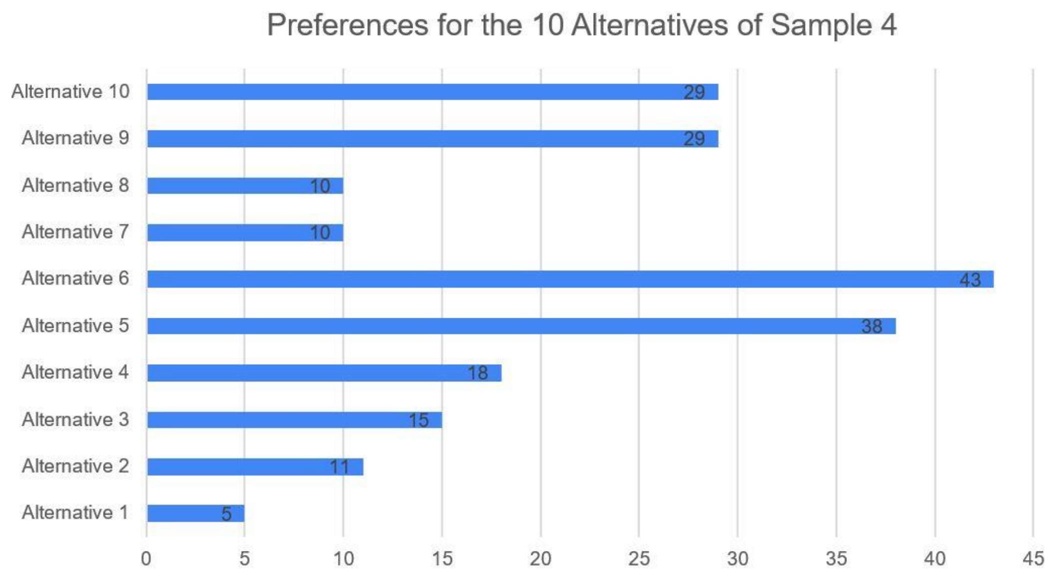


Figure 5.7. Listening test results of four preferences for Sample 4

In the following question of the second part of the listening test, participants are asked to choose their most preferable and least preferable alternatives out of the ten options. As seen below in Figure 5.8., Alternatives 5, 6, 9 and 10 have been the most desirable choices while Alternatives 1, 7 and 8 were highly disliked, hence least preferred.

On the final part of the test, listeners are asked to fill an acoustic evaluation form regarding their most preferred and least preferred alternatives of choice. As mentioned earlier in Section 4.3., the evaluation form aims to create a correlation between the objective acoustic parameters and subjective acoustic parameters. Participants are asked to fill out a semantic differential test that have questions with a five-point bipolar Likert scale.

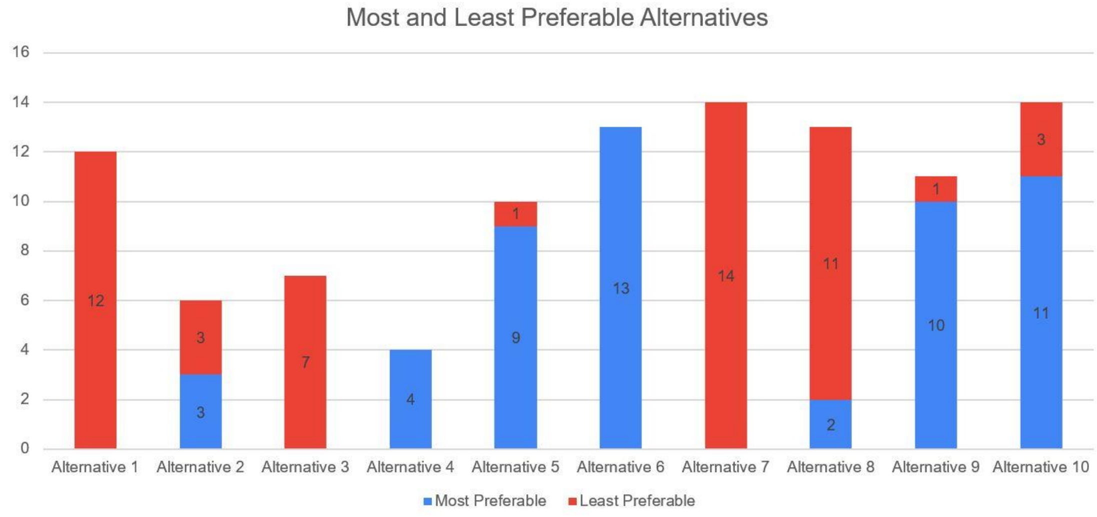


Figure 5.8. Listening test results of most and least preferable alternatives

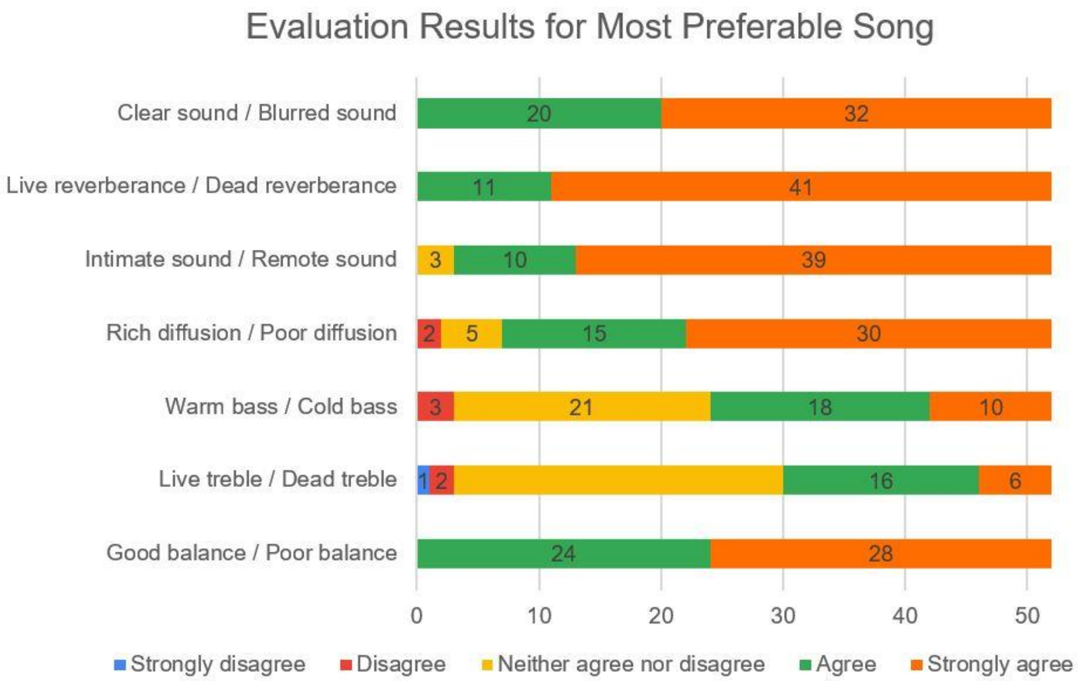


Figure 5.9. Listening test results of the evaluation for most preferable song

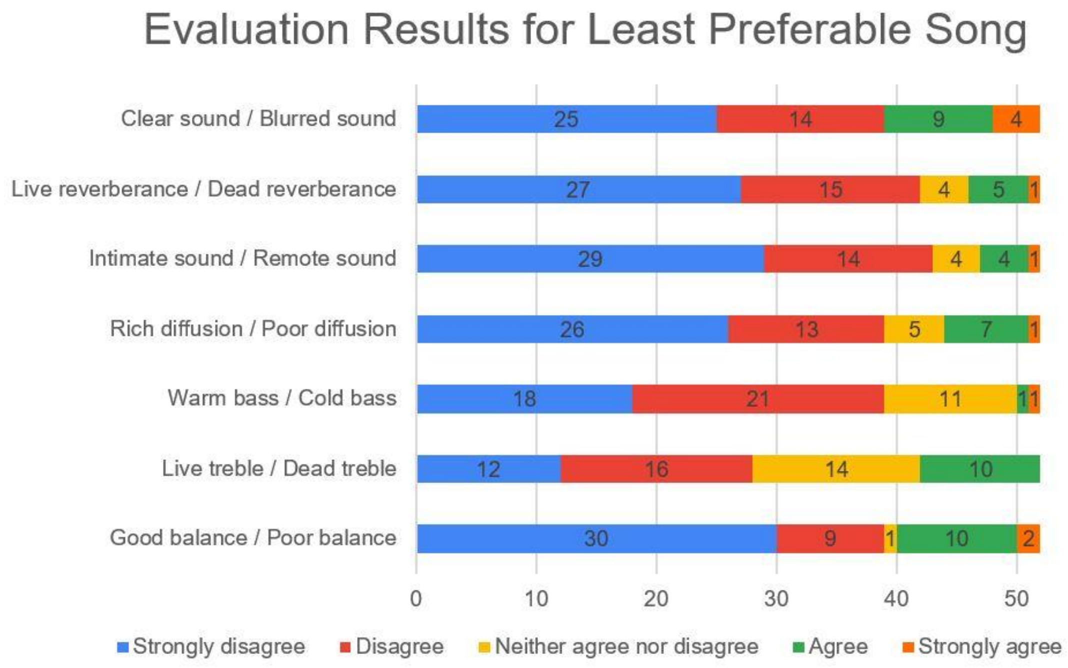


Figure 5.10. Listening test results of the evaluation for least preferable song

The questions on the evaluation form intend to find out preferences regarding clarity, reverberance, intimacy, diffusion, warmth and balance which can be linked to the objective parameters EDT, RT, C_{80}, D_{50}, BR and TR. Figure 5.9. shows the results of the evaluation form where listeners answered the questions for their most preferable choice, where Figure 5.10. presents the answers for their least preferable choice. It can be seen that most preferable songs yield noticeable positive feedback and can be considered a possible reference in terms of acoustic conditions for Turkish music.

Deriving from the results of the listening test, the auralisations that were made using the box room Alternatives 5, 6, 9 and 10 have delivered the most feasible outcomes. This gives the possibility to examine the objective acoustic parameters of the rooms and make potential assumptions regarding optimum conditions for TCM. In all four rooms, early decay times are 1,40 seconds at 500Hz, and 1,25 seconds at 1000Hz with the exception of Attempt 10, which is 1,34 seconds. Attempts 5, 6 and 9 have the same reverberation times being 1,31 seconds at 500Hz and 1,17 seconds at 1000Hz. Attempt

10 has a RT value of 1,31 seconds at 500Hz and 1,30 seconds at 1000Hz. C_{80} values are identical for each room at 500Hz, with a value of 0,50 dB. At 1000Hz, Attempts 5, 6 and 9 have a C_{80} value of 1,30 dB where Attempt 10 has a value of 0,60 dB. D_{50} values remain equal for Attempts 5 and 6, being 0,98 at 500Hz and 0,42 at 1000Hz. Attempt 9 has a D_{50} value of 0,38 at 500Hz and 0,42 at 1000Hz, while Attempt 10 has a value of 0,38 at both 500Hz and 1000Hz.

An important factor that distinguishes the four rooms from each other is the bass and treble ratios, which affect the warmth and brilliance parameters. Rooms with bass ratios higher than 1,0 are considered to be successful in terms of warmth. Similarly, treble ratios that are lower than 1,0 contribute to the warmth factor, as well. In Attempts 5 and 6, BR values are 1,44 and 1,10 respectively, while TR values are 0,93 in both. Attempt 10 has a BR value of 1,27 and a TR value of 1,12. Attempt 9 has the highest BR out of the four, with a value of 1,73; which may be considered slightly excessive. However, the test results indicate that most participants have considered the rooms to have warm bass and live trebles.

According to the listening test results, the assumptions that were made for optimum acoustic conditions for TCM may be summarized as follows. Reverberation times appear to give the best results between 1,10 and 1,30 seconds. Early decay times, being linked directly to RT, are considered to yield successful outcomes when they are at least 1,1 times higher than RT, in this case values between 1,20 and 1,40 is believed to be sufficient. According to Beranek (1996), optimum clarity values for performance spaces should be between -4 dB and +4 dB, while Barron (2009) suggests a range between -2 dB and +2 dB. According to the test results, clarity values tend to stay between -4 and +4 dB with the exception of Attempts 2 and 3. Hence, it is possible to say that the same principle that Beranek had proposed may be applied to TCM, as well. Bass ratios are observed to be the most efficient when kept between 1,10 and 1,40, while treble ratios should be maintained to be lower than 1,0. The proposed optimum acoustic parameters can be found in Table 5.6. below.

Table 5.6. *Proposed optimum acoustic parameters for Turkish classical music*

EDT (s)	***T_{30} (s)***	***C_{80}***	***D_{50}***	***BR***	***TR***
1,20 – 1,40	1,10 – 1,30	-4 to +4	0,38 – 0,42	1,10 – 1,40	< 1,0

Although the listening test results might give an idea on the optimum acoustic conditions for TCM, it should not be considered as a fully accurate resource for information. This is due to the fact that the auralisations were made in a box shaped room with definite dimensions. Since the quality of a room also depends on its size and shape, the parameters that were acquired from the listening test may not be applicable for every type of room, thus different rooms with different shapes and sizes may require different conditions for TCM to sound better. There is also the possibility of TCM not being suitable for certain room sizes or shapes. In order to overcome this complication, the suggested parameters should be applied in different room types in pursuance of confirming the proposed conditions. In this study, three different performance spaces are used for this goal. Existing parameters are modified by changing material absorption coefficients in the aim of achieving similar parameters that were most preferred in the listening test. Detailed information on the optimization of the rooms is presented in the next section of this thesis.

5.4. Determining Optimum Conditions for the Three Room Cases

The three performance spaces that were modelled in 3D modelling software were imported to Odeon for acoustic calculations and auralisations. Materials were assigned to surfaces to properly represent the existing acoustic properties of the rooms. The existing conditions are considered to be insufficient in order to provide an ideal listening experience for Turkish music performances. In order to find out whether this concern is accurate, the rooms need to be reconstucted to have optimum acoustic parameters that were discussed in the previous section. Once the auralisations are made in the modified rooms, comparisons between the two scenarios can be made.

The improvements of the rooms can be achieved by changing the reflective materials on the surfaces and calculating the acoustic parameters to see if the desired conditions can be met or not. Below in Table 5.7. are the materials that were changed in each room with their original and modified absorption coefficients for every octave band.

Table 5.7. *Absorption coefficients of existing and modified materials in three performance spaces*

Room	Surface type	Material	Absorption Coefficient							
			63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
ANKARA OPERA HOUSE	Walls	Wood cladding on concrete	0,42	0,42	0,21	0,10	0,08	0,06	0,06	0,06
		Modified	0,05	0,05	0,05	0,12	0,12	0,10	0,05	0,05
	Curtains (walls)	Heavy velvet curtain	0,14	0,14	0,35	0,55	0,72	0,70	0,65	0,65
		Modified	0,05	0,05	0,10	0,10	0,20	0,20	0,30	0,30
	Ceiling	Wood cladding on concrete with air gap between	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
		Modified	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
ESMMO CONFERENCE HALL	Walls	Plywood panel on concrete	0,42	0,42	0,21	0,10	0,08	0,06	0,06	0,06
		Modified	0,02	0,02	0,02	0,05	0,05	0,10	0,05	0,05
	Wall panels	Perforated gypsumboard	0,18	0,18	0,32	0,71	0,99	0,50	0,29	0,29
		Modified	0,02	0,02	0,02	0,05	0,05	0,10	0,05	0,05
AIR FORCE CONFERENCE HALL	Walls	Plywood panel on concrete	0,42	0,42	0,21	0,10	0,08	0,06	0,06	0,06
		Modified	0,40	0,40	0,30	0,25	0,20	0,20	0,10	0,10
	Wall panels	16-22mm wood facing	0,25	0,25	0,15	0,10	0,09	0,08	0,07	0,07
		Modified	0,40	0,40	0,30	0,25	0,20	0,20	0,10	0,10
	Ceiling	Wood cladding on concrete with air gap between	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
		Modified	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05

Ankara Opera House seems to be providing acceptable RT values for 500Hz and 1000Hz, however, EDT values and bass/treble ratios appear to be insufficient. In the improvement process, absorption coefficients in the low frequencies were decreased in order to enhance the reverberation times in the lower frequencies, thus increasing the BR values and warmth. Absorption was increased slightly in the high frequencies to keep the treble ratio under 1,0. In ESMMMO conference hall, RT values were found to be significantly lower than optimum, hence absorption coefficients were decreased globally to achieve a higher RT value that is in optimum range. Absorption coefficients in the lower frequencies were kept lower compared to the high frequencies in the aim of bringing BR and TR values near to optimum. In the Air Force conference hall, the total absorption of the room is slightly increased in order to provide feasible values for EDT and RT. BR and TR values were considered acceptable, however, in the modified room the BR value has slightly improved. The objective parameters of the existing rooms and their modified forms can be found in Table 5.8. below.

Table 5.8. *Acoustic parameters of performance spaces*

Room	**Type**	***EDT***		T_{30}		C_{80}		D_{50}		***BR***	***TR***
		500 Hz	**1000 Hz**	**500 Hz**	**1000 Hz**	**500 Hz**	**1000 Hz**	**500 Hz**	**1000 Hz**		
Ankara Opera House	Existing	0,81	0,74	1,24	1,28	5,8	6,4	0,62	0,66	0,98	1,00
	Modified	1,42	1,37	1,30	1,31	3,9	4,1	0,57	0,62	1,26	0,96
ESMMMO Conference Hall	Existing	1,33	1,23	0,98	0,88	2,4	3,7	0,50	0,58	1,08	1,03
	Modified	1,57	1,56	1,27	1,22	-0,6	0,5	0,37	0,41	1,13	0,86
Air Force Conference Hall	Existing	1,43	1,14	1,40	1,42	2,3	3,4	0,44	0,51	1,05	0,91
	Modified	1,32	1,30	1,26	1,22	3,0	4,0	0,47	0,52	1,27	0,92

5.5. Results of the Second Listening Test

For the second listening test, auralisations that were made in the three performance spaces were used. A total of 50 people took the listening test, who also participated in the first listening test, of which 5 of them were unavailable out of the 55.

Participants are asked to choose their preferable alternative of the 5 song samples that were played in each performance space, and fill the acoustic evaluation sheet for Sample 4 afterwards. Each sample was played first in the existing spaces, and later in the modified conditions of the spaces. Sample 4 was chosen for the evaluation questions due to it being asked in the first listening test, hence giving the possibility of an easier comparison between the two. Figures 5.11. to 5.13. show the results of the preferences of each sample played in each room.

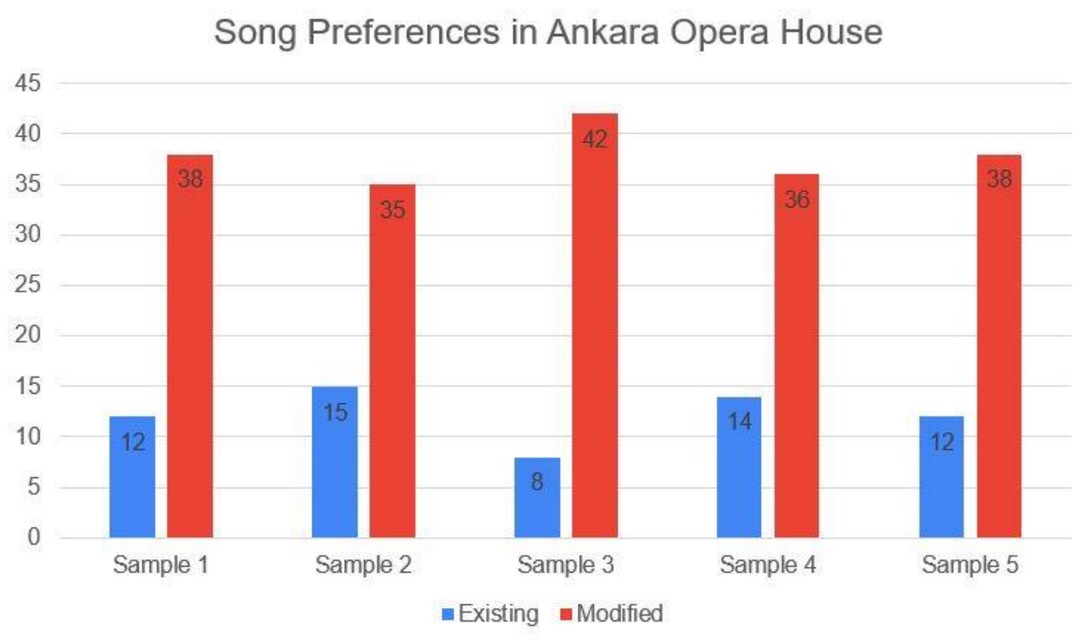


Figure 5.21. Listening test results of the song preferences in Ankara Opera House

The listening test results of the auralisations in Ankara Opera House have shown that a mean percentage of 75,6% of the population have chosen the modified conditions of the room for each sample as the most preferable, with a standard deviation of 4,8.

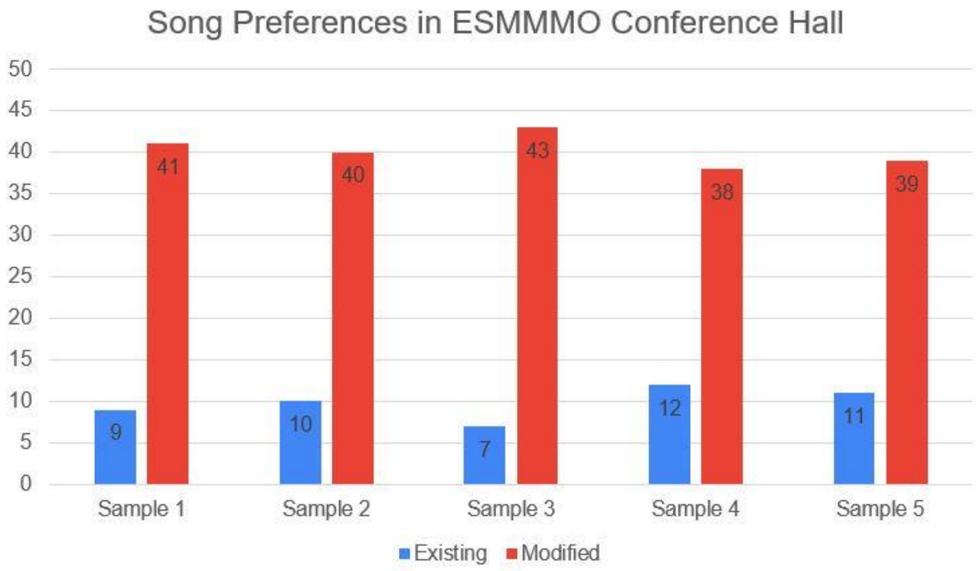


Figure 5.12. Listening test results of the song preferences in ESMMMO conference hall

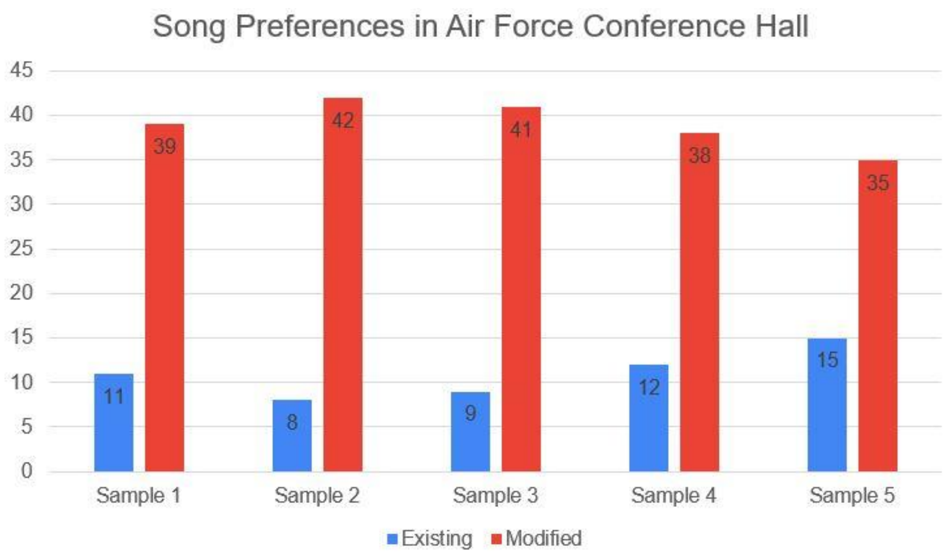


Figure 5.13. Listening test results of the song preferences in Air Force conference hall

In ESMMMO conference hall, the majority of the participants have chosen the modified conditions over the existing ones, with a mean percentage of 80,4% and a standard deviation of 3,4. Furthermore, a mean 78% of the participants have once more chosen the modified conditions in the Air Force conference hall, with a standard deviation value of 4,8.

5.6. Discussion

In Tables 5.9. to 5.12., the acoustic evaluation sheet results of each listening test are given respectively and comparisons are made in terms of acoustic evaluation criteria. Results from the anechoic box room, the existing performance spaces and the reconstructed performance spaces are given in the form of objective acoustic parameters and their relevant subjective parameters. Questions regarding subjective parameters are linked to the regarding objective parameters. Participants who answered as "strongly agree" or "agree" in the evaluation sheet are calculated as a percentage of the total participants. Results higher than 50% are considered to be successful in their respective parameter. For the EDT, RT, C_{80} and D_{50} values, the mean of 500Hz and 1000Hz are presented as an average value in the tables.

Table 5.9. *Correlation of objective and subjective parameters in the anechoic box room*

		Least Preferable (Alternative 7)		**Most Preferable (Alternative 6)**	
Parameter	**Subjective Equivalent**	**Objective Value**	**Evaluation Score**	**Objective Value**	**Evaluation Score**
EDT (avg.)	Liveness, brilliance	1,65 s	11%	1,32 s	86%
RT (avg.)	Liveness, brilliance	1,55 s	11%	1,24 s	100%
C_{80} (avg.)	Clarity	-1,10 dB	25%	0,90 dB	100%
D_{50} (avg.)	Intelligibility	0,32	23%	0,40	100%
BR	Warmth	1,36	3%	1,10	53%
TR	Brilliance	0,93	19%	0,93	42%

The results from the anechoic box room are shown in Table 5.9. The evaluation sheet results from the least favorable alternative and the most favorable alternative that were shown in Figures 5.8. and 5.10. are compared in terms of acoustic parameters and their equivalent subjective parameter. Since there is a significant difference between the acoustic parameters of the two alternatives, the evaluation results were also considerably different from each other, hence, this correlation is not believed to be fully accurate and representative of a realistic solution for TCM acoustic conditions. In addition, the BR and TR values of the most favorable alternatives do not seem to meet the predicted outcomes, due to the fact that the answers to the questions regarding BR and TR mostly involved a "neither agree or disagree" answer, which made a neutral effect on the evaluation points, causing them to drop.

More accurate results are gathered from the second listening test, in which the existing and modified room conditions are somewhat closer to each other, compared to the anechoic alternatives. The results from the three rooms are presented in Tables 5.10., 5.11. and 5.12. below.

Table 5.10. *Correlation of objective and subjective parameters in Ankara Opera House*

		Existing Model		**Modified Model**	
Parameter	**Subjective equivalent**	**Objective value**	**Evaluation score**	**Objective value**	**Evaluation score**
EDT (avg.)	Liveness, brilliance	0,77 s	24%	1,39 s	84%
RT (avg.)	Liveness, brilliance	1,26 s	64%	1,30 s	82%
C_{80} (avg.)	Clarity	6,1 dB	32%	4,0 dB	76%
D_{50} (avg.)	Intelligibility	0,64	42%	0,59	74%
BR	Warmth	0,98	36%	1,26	74%
TR	Brilliance	1,00	40%	0,96	70%

Table 5.11. *Correlation of objective and subjective parameters in ESMMMO conference hall*

		Existing Model		Modified Model	
Parameter	**Subjective equivalent**	**Objective value**	**Evaluation score**	**Objective value**	**Evaluation score**
EDT (avg.)	Liveness, brilliance	1,38 s	48%	1,56 s	92%
RT (avg.)	Liveness, brilliance	0,93 s	38%	1,24 s	90%
C_{80} (avg.)	Clarity	3 dB	54%	-2,75 dB	52%
D_{50} (avg.)	Intelligibility	0,54	58%	0,39	50%
BR	Warmth	1,08	52%	1,13	72%
TR	Brilliance	1,03	44%	0,86	80%

Table 5.12. *Correlation of objective and subjective parameters in Air Force conference hall*

		Existing Model		Modified Model	
Parameter	**Subjective equivalent**	**Objective value**	**Evaluation score**	**Objective value**	**Evaluation score**
EDT (avg.)	Liveness, brilliance	1,28 s	42%	1,31 s	76%
RT (avg.)	Liveness, brilliance	1,41 s	58%	1,24 s	88%
C_{80} (avg.)	Clarity	2,8 dB	52%	3,5 dB	70%
D_{50} (avg.)	Intelligibility	0,47	60%	0,49	60%
BR	Warmth	1,05	48%	1,27	76%
TR	Brilliance	0,91	68%	0,92	72%

In Figure 5.14., a summary of the evaluation scores between the existing and modified conditions of the three selected rooms are presented. The results show that each parameter has received a greatly improved feedback in Ankara Opera House when the acoustic conditions were enhanced in the modified room to meet the optimum ranges.

Correlations of the ESMMMO conference hall have also provided improved conditions and positive responses from the listeners. The only exceptions were C_{80} and D_{50} values where the C_{80} value has receive a 2% decrease in the evaluation score and the D_{50} parameter evaluation score had a downfall of 8%.

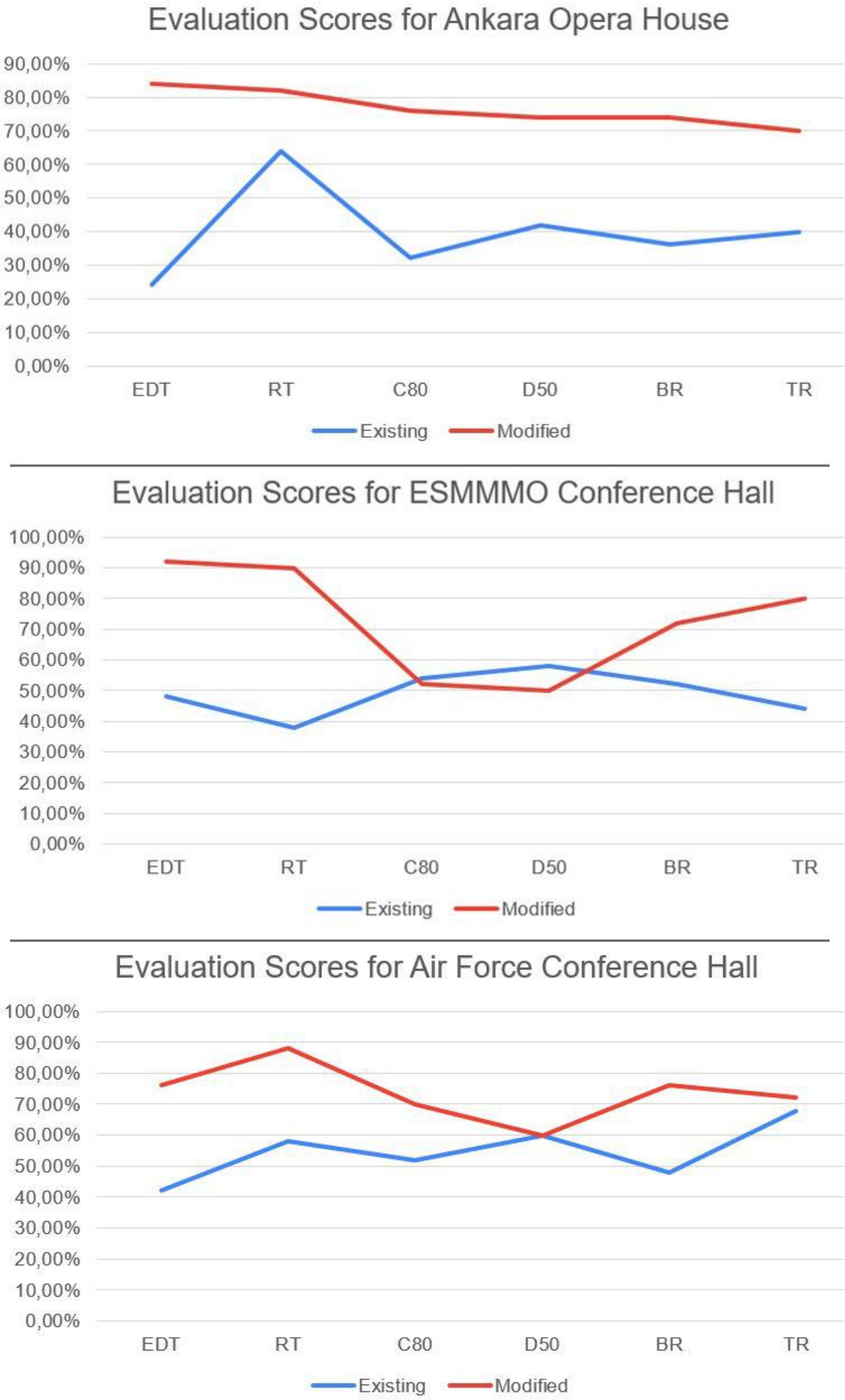


Figure 5.14. Evaluation scores of the three performance spaces

Listeners have reacted more positively towards a +3 dB C_{80} value instead of the modified -2,75 dB in ESMMMO conference hall, whereas a value of 0,54 was more preferable than 0,39 for D_{50}. This points out to the fact that the proposed D_{50} values between 0,38 and 0,42 for TCM may not be optimum and the accepted optimum range of D_{50} for classical music and opera may also apply to TCM, which is between 0,45 and 0,60. The C_{80} parameter is also observed to be unsuccessful below 0 dB, which might support the optimum range of C_{80} should be between 0 and +4 dB for TCM, that was previously proposed by Özçevik & Yüksel Can (2015).

The TR parameter has received a significant increase which provided an evaluation score of 80%, with a value of 0,86. When compared to Ankara Opera House, which received a score of 70% with a TR value of 0,96, it may be assumed that the decrease in the TR parameter has created better conditions for TCM.

RT values have provided a positive feedback in all three rooms with values of 1,30, 1,24 and 1,24 seconds respectively. This can be interpreted as a successful optimum value, which supports the proposed range between 1,10 and 1.30 seconds for TCM.

EDT values have the highest evaluation score in ESMMMO conference hall with a percent of 92% and a value of 1,56 seconds. The Ankara Opera House EDT values have also received a plausible score of 84% with a value of 1,39 seconds. EDT values that are 1.1 times higher than RT are currently accepted as successful, however, in this case, even though all three results have provided acceptable conditions, 1,39 and 1,56 seconds received better responses, hence it may be assumed that when rounded up, values between 1,40 and 1,60 seconds are close to optimum conditions for TCM, which is similar to the optimum EDT values of opera that are accepted between 1,40 and 1,75 seconds.

Differences between evaluation scores of BR values can be clearly observed in Ankara Opera House where the existing BR value which is lower than 1,0 has received a low score of 36% while a modified value of 1,26 received a score of 74%. ESMMMO conference hall and Air Force conference hall also present similar positive feedback towards BR values which receive successful evaluation scores with values of 1,13 and 1,27 respectively. It can be assumed that BR values between 1,10 and 1,30 may be considered to be successful values regarding optimum TCM conditions.

The results and outputs from the listening test may be summarized as the following:

- EDT values are considered as successful when they are 1.1 times or higher than RT values. For TCM, values between 1,39 and 1,56 seconds have presented the most successful acoustic conditions.
- RT values between 1,10 and 1,30 seconds may be accepted as an optimum range for TCM. Values lower than 1,00 seconds are believed to be insufficient.
- C_{80} values are best observed between 0 dB and +4 dB. Values lower than 0 dB may be acknowledged as unsuccessful for TCM.
- D_{50} values between 0,38 and 0,42 that were previously proposed have turned out to yield a slightly more negative feedback than values of 0,49 and 0,59. Values that were accepted as optimum for classical music and opera may be acknowledged for TCM as well, which are between 0,45 and 0,60.
- BR values which are higher than 1,0 can be considered acceptable for TCM. Values between 1,10 and 1,30 may be assumed as an optimum range, as well.
- TR values which are higher than 1,0 present unsuccessful results for TCM. Values lower than 1,0 may be considered as an optimum range.

Table 5.13. presents the proposed optimum conditions for Turkish classical music.

Table 5.13. *Proposed optimum conditions for Turkish classical music*

EDT	**T_{30}**	**C_{80}**	**D_{50}**	**BR**	**TR**
1,40 – 1,60 s	1,10 – 1,30 s	$0 > C_{80} > +4$ dB	0,45-0,60	1,1-1,3	TR < 1,0

The initial listening test aims at creating a foundation to understand the basic requirements that were needed for TCM. The second listening test focuses on implementing the first test results in case scenarios in order to test and confirm whether or not the said results and assumptions could be feasible. The outcomes have provided that the parameters that were proposed in Table 5.13. are applicable and may be referred to in scenarios where a performance hall that houses Turkish music is to be designed and acoustic conditions should be met accordingly.

A guideline may be proposed by taking into account the results of each room that was analyzed, in the aim of determining the main requirements when designing a space that is going to be used for TCM performances. The parameters of the three analyzed rooms are shown in Table 5.14.

Table 5.14. *Parameters and conditions of the selected three performance spaces*

Room	**Size**	**Shape**	**Capacity**	**EDT**	**RT**	**C_{80}**	**D_{50}**	**BR**	**TR**
Ankara Opera House	5430 m^3	Shoebox	698 persons	1,39 s	1,30 s	4,0 dB	0,59	1,26	0,96
ESMMMO Conference Hall	3575 m^3	Fan shaped	264 persons	1,56 s	1,24 s	-2,75 dB	0,39	1,13	0,86
Air Force Conference Hall	2345 m^3	Box shaped	391 persons	1,31 s	1,24 s	3,5 dB	0,49	1,27	0,92

Assumptions that are made in terms of architectural design criteria and acoustic conditions may be summarized as follows:

- Previous studies by Özçevik & Yüksel Can (2015) have proposed that TCM is not suitable for rooms bigger than 1000 m^3 in volume. In this study, three rooms that have a large volume have been analyzed and outputs have presented that when required conditions are met, TCM may be performed in large volumes without the need of additional amplification.

- In Ankara Opera House, parameters that are shown in the previous tables are found to be plausible for TCM performances. The shoebox type room can be considered as successful for TCM, which supports the objective parameter values and complements rooms designed for music.
- C_{80} and D_{50} values in ESMMMO conference hall were found to be insufficient. This may be due to the fan shaped room type, which affects the late reflections of the sound coming from its source. The behavior of reflected sounds need to be analyzed before designing a room for TCM in order to eliminate unfavorable conditions regarding clarity, due to the presence of vocals.
- Similar to Ankara Opera House, objective parameters are found to be acceptable for Air Force conference hall, as well. This room is almost half the size of Ankara Opera House in volume, which may make it easier to achieve optimum conditions. The box shape is found to be a successful room type.
- Even though TCM has similar elements with opera, the characteristics of TCM are different. This points out to the fact that traditional opera houses with horseshoe plan types might not be acceptable for TCM, and room shapes similar to rooms for music may be considered more feasible for TCM performances. Further investigation is necessary regarding this matter.
- In all three cases, materials that are used in reflective surfaces need to be chosen in the aim of acquiring the proposed parameters. Highly reflective materials should be used in large volumes to be able to reach the desired EDT and RT values. Materials that have a relatively low absorption coefficient in low frequencies, such as plates and flat surfaces, should be preferred in side walls and ceilings order to achieve an optimum BR value. For optimizing C_{80} and D_{50} values, materials should be assigned symmetrically to side walls to avoid unbalanced reflections.

This study was aimed to serve as a guideline for creating satisfactory conditions when designing a room that specifically serves for Turkish classical music. It is considered that this study may be the first step towards reaching a standard layout for performance spaces dedicated to TCM. The case rooms were selected randomly as to reflect different room types and behaviors. When modifying the existing spaces, room sizes were not changed as this matter would complicate the outcome process and could have resulted in a high number of evaluation necessities. Hence, the only modifications were made in the materials of the rooms, in order to keep the comparisons of each space in a more controlled environment.

Future studies may have a chance of further examination on the subject by following the same process that was presented in this thesis. Nevertheless, a more extensive assessment various rooms with different conditions is required to achieve an acknowledged definition of the acoustic conditions needed for TCM. Previous studies on the matter have analyzed traditional spaces where Turkish music used to be performed in the Ottoman period and have made assumptions on whether said spaces were suitable for TCM or not. However, these studies have only included a limited number of cases, where some were found to be acceptable and some were not, even though Turkish music used to be performed traditionally in all the examined cases.

Turkish music is considered a comprehensive type of music that has different styles according to its purpose, such as Turkish classical music, religious Turkish music, or Turkish folk music. All of these styles are performed in different spaces. For instance, religious music is usually played in religious building such as mosques or dervish lodges, while folk music may be played in residential spaces or even outdoors. This brings out the question of further examinations regarding the future of Turkish music acoustics. In this study, only a portion of aforementioned styles were analyzed in terms of room acoustic requirements. Further studies regarding different Turkish music styles and different rooms may be conducted in the aim of broadening the area of interest in the field of Turkish music acoustics.

CHAPTER 6

CONCLUSION

In this chapter, a brief summary of the study is presented and suggestions for possible future studies have been made. Any limitations throughout the study is also discussed in detail throughout the chapter.

6.1. Summary

Since the end of the 19th century and the beginning of the 20th century, the field of acoustics had become a science and a considerable amount of research has been done in various branches, such as mechanical engineering, psychology, music and architecture. In the field of architecture, room acoustics has been studied in the aim of improving acoustic quality and creating more successful performance spaces, which were a part of the environment throughout centuries, continuing to develop from the early Greek period up to this day. Along with western classical music, opera, drama and speech, Turkish classical music is being performed for centuries as well, and yet acoustic studies are very limited in this particular type of performance. This study aims to provide a closer look to TCM and to be of guidance for TCM to be studied in the field of acoustics, apart from its musical research area.

The first step for this study to be carried out is to investigate the attributes of Turkish music and find similarities and differences between other performance types. An extensive review of literature has been conducted concerning the history of Turkish music and its characteristics. It was found that Turkish music had gone through changes throughout history regarding its purpose, teaching methods and performing styles. One main aspect that differentiates TCM from western music is the presence of makams. While western music uses an 8-note system, a total of 52 makams are present in TCM. Another aspect is the size of a TCM orchestra, which is smaller than a symphony orchestra, thus TCM was commonly practiced and performed in smaller rooms. Instruments of TCM differ from western music as well, and an important distinguishing element is the fact that TCM is monophonic, whereas western music is polyphonic. While western music is taught and performed with a note system, TCM is most commonly taught by the "meşk" method which involves a teacher and a student where learning is done by listening and repeating.

The basic acoustic qualities a performance space depend on its acoustic parameters. Acoustic parameters can be analyzed as objective parameters and subjective parameters. The quality of a room relies on its shape and size, regarding of its function the shape and size of the room differs. Western classical music is best listened on rectangular halls while opera requires horseshoe rooms. The dimensions of a room also affect objective parameters, which directly affect subjective parameters. A comprehensive investigation has been done regarding room acoustic parameters, where definitions and explanations have been made for objective parameters which are reverberation time (RT), early decay time (EDT), clarity (C_{80}), definition (D_{50}), early lateral energy fraction (LF_{80}), late arriving lateral energy (LG_{80}) and bass and treble ratios (BR, TR). Subjective parameters such as reverberance, clarity, warmth, intimacy, listener envelopment and balance were examined.

Apart from the examination of TCM with its history, main characteristics and differences from other performance types, additional analyses were carried out concerning the acoustic properties of TCM. Frequency spectrum analyses were made for western classical music, opera and TCM, where 100 samples of music regarding each type of performance were examined in terms of frequency spectra. It was found that low frequencies tend to be more dominant in TCM, percussions and vocals are commonly the main assertive elements and TCM songs usually follow a homogenous pattern, where songs are more dynamic and versatile.

Deriving from the information that was gathered throughout the study, experiments were made using auralisations of Turkish music recordings, in the aim of getting closer to determining optimum acoustic conditions. Four reference auralisations were made in a box shaped room that has similar conditions to an anechoic chamber. Afterwards, ten alternatives which have different acoustic parameters were created and auralisations were made for each alternative.

The auralisations were used for a listening test to try to discover which alternatives were the most successful in terms of acoustic quality regarding TCM. The listening test was aimed to link objective parameters to subjective parameters of the listeners. Results have shown that references 5, 6, 9 and 10 had the most preferable conditions.

Acquiring from the results, assumptions were made regarding optimum acoustic parameters for TCM. Reverberation time was found to be most successful between 1,10 and 1,30 seconds, where early decay times are best observed between 1,20 and 1,40 seconds. C_{80} values have yielded the best results when they are between -4 dB and +4 dB, while the most acceptable D_{50} values are between 0,38 and 0,42. Bass ratios between 1,10 and 1,40 together with treble ratios that are lower than 1,0 provide warm bass and live treble experiences.

The results of the listening test have provided optimum conditions for TCM, however, since they were made in a box shaped room, they merely qualified as assumptions. A second listening test was conducted using auralisations made in three different existing performance spaces. The performance spaces were improved in terms of acoustic quality and conditions similar or close to optimum were achieved. Listeners are asked to choose between the existing conditions and the improved conditions by listening to samples that were played in each scenario. Results have shown that the majority of the participants preferred the improved conditions over the existing ones.

Correlations were made from the results of the second listening test, where the evaluation scores of each room is compared between the existing and improved conditions. The results showed that the improved conditions received a more positive feedback compared to the existing conditions. Following the correlations, improvements were made in the earlier proposed conditions for TCM. RT values are accepted optimum between 1,10 and 1,30 seconds, where EDT values between 1,40 and 1,60 seconds are considered to be successful. C_{80} values provide the best results between 0 dB and +4 dB and D_{50} values between 0,45 and 0,60 are accepted as optimum, which are the same accepted values for classical music and opera. BR values between 1,1 and 1,3 along with TR values that are lower than 1,0 are acknowledged to give successful results regarding conditions for TCM.

When designing a space for TCM, rectangular box shaped rooms should be preferred in order to achieve better acoustic conditions. Late reflections should be taken into account to provide better results for C_{80} and D_{50} values. Reflective materials that have low absorption coefficients in low frequencies should be used in walls and ceilings to keep the BR values in optimum range and achieve plausible RT and EDT values.

6.2. Limitations and Recommendations

This study was done as a master's thesis, and due to limited facilities and time, it is believed that the subject has a much bigger potential and can be focused more in-depth in the future. Anechoic recordings were difficult to obtain, which led to the necessity of support from previous researchers.

In a more intensive study, recordings may be taken in order to reflect various different styles of TCM, such as the presence of a choir or a bigger orchestra. Experiments and listening tests may be done in other performance spaces as to bring out even more accurate results, getting one step closer to determine a standard for acoustic conditions regarding TCM. This study is believed to be the first step among the many steps into achieving that goal.

REFERENCES

Ak, A. Ş. (2014). *Türk Musikisi Tarihi.* Ankara: Akçağ Yayınları.

Akkoç, C. (2002). Non-Deterministic Scales Used in Traditional Turkish Music. *Journal of New Music Research*, 285-293.

Aletta, F., Botteldooren, D., Thomas, P., Vander Mynsbrugge, T., De Vriendt, P., Van de Velde, D., & Devos, P. (2017). Exploring the soundscape quality of five nursing homes in Flanders (Belgium): preliminary results from the AcustiCare project. *Internoise* (s. 31-40). Hong Kong: Internoise.

Aşıroğlu, S. C. (2009). *Klasik Türk Müziğinde Stratejik Pazarlamanın Rolü.* İstanbul: Haliç University, Graduate School of Social Sciences, master's thesis.

Aybars, B. (2008). *Türk Musikisi Temel Bilgileri.* İstanbul: İkinci Adam Yayınları.

Bahalı, S., & Tamer-Bayazıt, N. (2017). Soundscape research on the Gezi Park – Tunel Square Route. *Applied Acoustics*, 260-270.

Barron, M. (1993). *Auditorium Acoustics and Architectural Design.* London: Taylor & Francis.

Behar, C. (1993). *Zaman-Mekan- Müzik.* İstanbul: AFA Yayıncılık.

Behar, C. (1998). *Aşk Olmayınca Meşk Olmaz.* İstanbul: Yapı Kredi Yayınları.

Behar, C. (2015). *Osmanlı/Türk Musikisinin Kısa Tarihi.* İstanbul: Yapı Kredi Yayınları.

Beranek, L. (1996). *Concert and Opera Halls: How They Sound.* New York, USA: Acoustical Society of America.

Beranek, L. (2004). *Concert Halls and Opera Houses: Music, Acoustics, and Architecture.* New York, USA: Springer - Verlag.

Bingöl, E. (1999). *Türk Musikisinde Makamlar ve Seyir Örnekleri.* İstanbul: Bakırköy Musiki Vakfı Yayınları.

Bissinger, G., & Mores, R. (2015). Model-based auralizations of violin sound trends accompanying plate-bridge tuning or holding. *JASA Express Letters*, 293-299.

Bozkurt, B. (2008). An Automatic Pitch Analysis Method for Turkish Maqam Music. *Journal of New Music Research*, 1-13.

Bradley, J. S., & Soulodre, G. A. (1995). Objective measures of listener envelopment. *Journal of Acoustical Society of America*, 98.

Can, M. C. (2001). *Orta Asya Türk Topluluklarında Müzik.* Ankara: "History of music" lecture notes.

Can, M. C. (2001). *XV. Yüzyıl Türk Musıkisi Nazariyatı (Ses Sistemi).* İstanbul: University of Marmara, Graduate School of Social Sciences, PhD. Thesis.

Can, M. C., & Levedoğlu, N. O. (2002). Geleneksel Türk Sanat Müziği Terminolojisinde Çok Kültürlü Unsurlar. *Gazi Eğitim Fakültesi Dergisi*, 239-245.

Cannam, C., Landone, C., & Sandler, M. (2010). Sonic Visualiser: An Open Source Application for Viewing, Analysing, and Annotating Music Audio Files. *Proceedings of the ACM Multimedia 2010 International Conference.* Firenze: MM '10 ACM Multimedia Conference. https://sonicvisualiser.org/. adresinden alındı

Cavanaugh, W., & Wilkes, J. (1999). *Architectural Acoustics.* New Jersey: John Wiley & Sons.

Cerwén, G. (2016). Urban soundscapes: a quasi-experiment in landscape architecture. *Landscape Research*, 1-14.

Costa, Y. M., Oliveira, L. S., Koericb, A. L., & Gouyon, F. (2011). Music genre recognition using spectrograms. *18th International Conference on Systems, Signals and Image Processing.* Sarajevo, Bosnia: IEEE.

Egan, D. (2007). *Architectural Acoustics.* New York, USA: Mc Graw Hill.

Elson, A. (1921). Architectural Acoustics. *The Musical Quarterly*, 469-482.

Everest, F. A., & Pohlamann, K. C. (2009). *Master Handbook of Acoustics.* New York, USA: The McGraw-Hill Companies.

Gade, A. C. (1989). Investigations of Musicians Room Acoustic Conditions in Concert Halls, II: Field Experiments and Synthesis Results. *Acoustica*, 249-262.

Gade, A. C. (2007). *Acoutics in Halls for Speech and Music Springer Handbook of Acoustics.* New York: Springer Science+Business Media.

Gedik, A. C., & Bozkurt, B. (2009). Evaluation of the Makam Scale Theory of Arel for Music Information Retrieval on Traditional Turkish Art Music. *Journal of New Music Research*, 103-116.

Gürbüz, H. (2010). *Meşk Sistemi, Türk Musikisine Katkıları Ve Günümüze.* İstanbul: Haliç University, Graduate School of Social Sciences, master's thesis.

Haan, C. H. (1993). *Geometry As a Measure of Acoustical Quality of Auditoria.* Sydney, Australia: University of Sydney, PhD.

Harriet, S., & Murphy, D. (2015). Auralisation of an Urban Soundscape. *Acta Acustica United with Acustica*, 798-810.

Hawkes, R. J., & Douglas, H. (1970). Subjective Acoustic Experience in Concert Auditoria. *Architectural Research and Teaching*, 34-45.

Johnson, K. (2011). *Acoustic and Auditory Phonetics.* Hoboken, NJ: Wiley - Blackwell.

Kara, E. (2009). *Valensiya Santa Anna Şapeli'nin Restorasyon Sonrası Akustik Değerlendirmesi.* İstanbul: Yıldız Technical University, Graduate School of Natural and Applied Sciences, master's thesis.

Karamahmutoğlu, G. (2014). Tanzimat Dönemi'nde Müzik, Dönem Padişahları ve Müzik Anlayışları. *Yeni Türkiye Dergisi Türk Musikisi Özel Sayı*, 563.

Kartal, E. (2012). *Türk Müziği Enstrümanlarının Frekans Aralıkları.* İstanbul: Özgür Yayınları.

Kaygusuz, N. (2014). 19. Yüzyıldan 21. Yüzyıla Türk Müziğinin Kısa Bir Hikayesi. *Yeni Türkiye Dergisi Türk Musikisi Özel Sayı*, 11-13.

Kleiner, M. (2012). *Acoustics and Audio Technology.* Ft. Lauderdale: J. Ross Publications.

Kuttruff, H. (1991). *Room Acoustics, Third Edition.* London, UK: Elsevier Applied Science.

Kuttruff, H. (2006). *Acoustics, an Introduction.* Florida: CRC Press.

Kwon, Y., & Siebein, G. (2007). Chronological Analysis of Architectural and Acoustical Indices in Music Performance Halls. *Journal of Acoustic Society of America*, 2691-2699.

Ladefoged, P. (1995). *Elements of Acoustic Phonetics.* Chicago: The University of Chicago Press.

Ladefoged, P., & Johnson, K. (2010). *A Course in Phonetics.* Wadsworth: Michael Rosenberg.

Lewis, B. (1968). *The Arabs in History.* London: Hutchinson University.

Long, M. (2006). *Architectural Acoustics.* Burlington, MA: Elsevier Academic Press.

Maekawa, Z., & Lord, P. (1994). *Environmental and Architectural Acoustics.* London, UK: E & FN Spon Press.

Malecki, P. (2015). Spatial Impulse Response Assessment in Room Acoustics Auralization. *Acta Physica Polonica A*, 17-21.

Malm, W. P. (1967). *Music Cultures of the Pacific, The Near East, and Asia.* New Jersey: Prentice-Hall.

Mehta, M., Johnson, J. A., & Rocafort, J. (1999). *Architectural Acoustics: Principles and Design.* New Jersey, USA: Prentice Hall.

Mommertz, E. (2009). *Acoustics and Sound Insulation.* Regensburg: Aumüller Druck.

Morales, A. R. (2013). A new method for auralisation of airborne sound insulation. *Applied Acoustics*, 116-121.

Örün, G. (2011). *ACOUSTICAL ANALYSIS AND TAXONOMY OF PERFORMANCE HALLS IN EARLY REPUBLICAN PERIOD IN ANKARA: RESIM HEYKEL MÜZESİ, KÜÇÜK TİYATRO AND OPERA.* Ankara: Middle East Technical University, Graduate School of Natural and Applied Sciences, Ms. thesis.

Özcan, N. (2014). Türk Musikisinin Abide Şahsiyetlerinden Hamamizade İsmail Dede Efendi. *Yeni Türkiye Dergisi Türk Musikisi Özel Sayı*, 433.

Özçevik, A., & Yüksel Can, Z. (2012). *A field study on the subjective evaluation of soundscape.* Nantes, France: Société Française d'Acoustique.

Özçevik, A., & Yüksel Can, Z. (2015). An Evaluation of Room Acoustics in Rooms Used for Turkish Melodic Music. *Megaron*, 195-204.

Özgür, Ü., & Aydoğan, S. (2015). *Gelenekten Geleceğe Makamsal Türk Müziği.* İstanbul: Arkadaş Yayınları.

Özkan, H. Ö. (2013). *Türk Musikisi ve Nazariyatı ve Usülleri Kudüm Velveleleri.* İstanbul: Ötüken Neşriyat.

Paçacı, G. (1999). *Cumhuriyet'in Sesleri.* İstanbul: Tarih Vakfı Yurt Yayınları.

Say, A. (2002). *Müziğin Kitabı.* Ankara: Müzik Ansiklopedisi Yayınları.

Sezgin, B. S. (1982). Düşündüklerimiz. *Sanat ve Kültürde Kök*, Issue 14.

Songar, A. (1988). *Türk Müziği İle Batı Müziğinin Ses Sistemlerinin İnformatif Değer Bakımından Karşılaştırılması.* İstanbul: 1. Müzik Kongresi.

Stevens, K. N. (1999). *Acoustic Phonetics.* Cambridge, Mass.: MIT Press.

Tanrıkorur, C. (2011). *Osmanlı Dönemi Türk Musikisi.* İstanbul: Dergah Yayınları.

Tura, Y. (1988). *Türk Musikisinin Meseleleri.* İstanbul: Pan Yayıncılık.

Turabi, A. H. (2004). *İbn-i Sina Musiki.* İstanbul: Litera Yayıncılık.

Türk, E. (2011). *İstanbul'daki Salonların Akustik Kalitesinin İncelenmesi ve Değerlendirilmesi.* İstanbul: Yıldız Technical University, Graduate School of Natural and Applied Sciences, master's thesis.

Uçan, A. (2000). *Türk Müziği Kültürü.* İstanbul: Müzik Ansiklopedisi Yayınları.

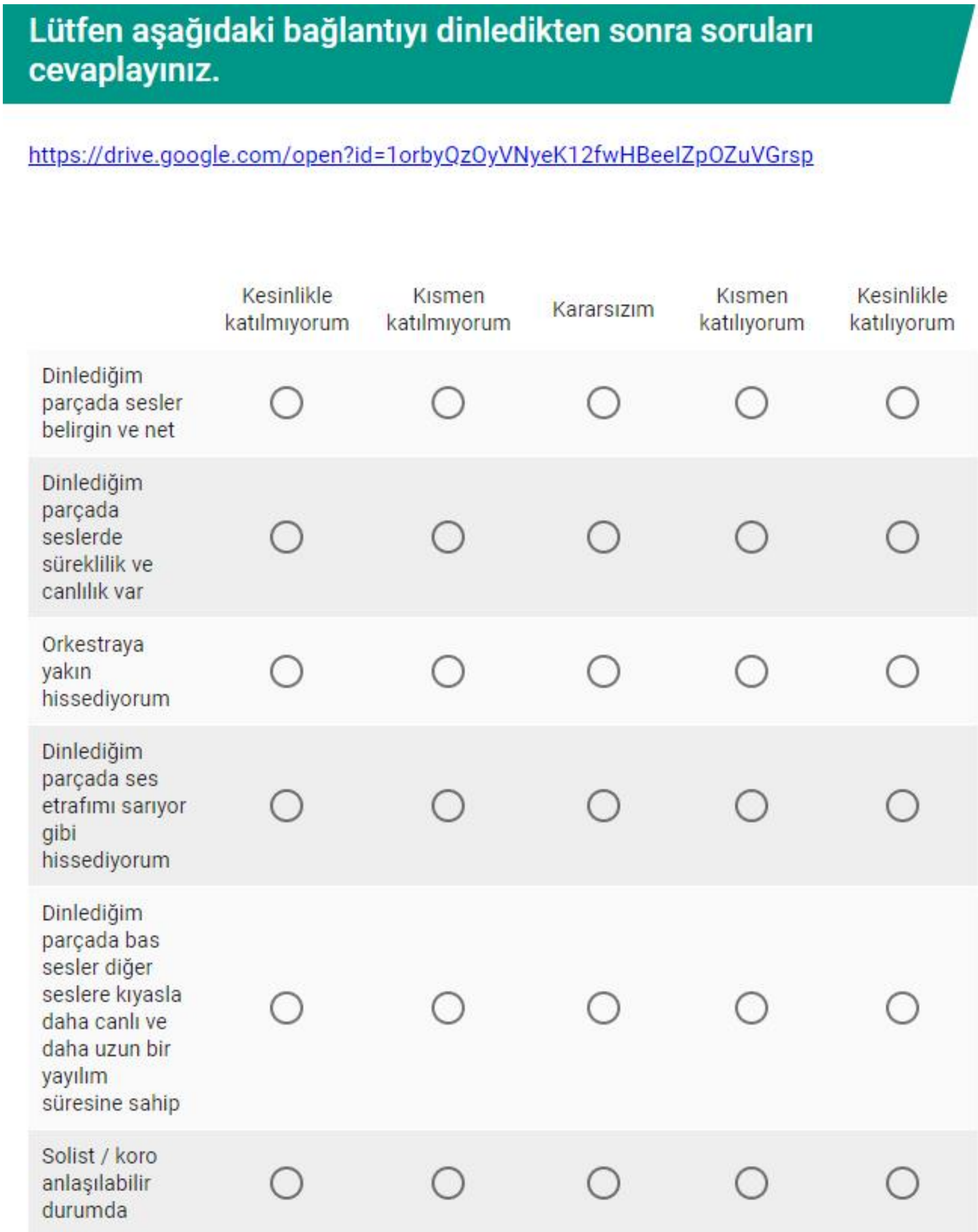
Ugan, K. Z. (1988). *Mukaddime (translation).* İstanbul: Şark İslam Klasikleri.

Yavaşça, A. (1981). Türk Müziğinde Tavır. *Sanat ve Kültürde Kök*, Issue 1.

Yener, S. (2014). Türk Müziğinin Tarihi Gelişimi ve Müziksel Kimlik. *Yeni Türkiye*, 11-13.

APPENDICES

A. BLANK SHEET OF ACOUSTIC EVALUATION SURVEY



Lütfen aşağıdaki bağlantıyı dinledikten sonra soruları cevaplayınız.

https://drive.google.com/open?id=1orbyQzOyVNyeK12fwHBeelZpOZuVGrsp

	Kesinlikle katılmıyorum	Kısmen katılmıyorum	Kararsızım	Kısmen katılıyorum	Kesinlikle katılıyorum
Dinlediğim parçada sesler belirgin ve net	○	○	○	○	○
Dinlediğim parçada seslerde süreklilik ve canlılık var	○	○	○	○	○
Orkestraya yakın hissediyorum	○	○	○	○	○
Dinlediğim parçada ses etrafımı sarıyor gibi hissediyorum	○	○	○	○	○
Dinlediğim parçada bas sesler diğer seslere kıyasla daha canlı ve daha uzun bir yayılım süresine sahip	○	○	○	○	○
Solist / koro anlaşılabilir durumda	○	○	○	○	○

Figure A.1. Blank sheet of acoustic evaluation survey

B. SPECTROGRAM VIEWS OF SONGS

Classical Music

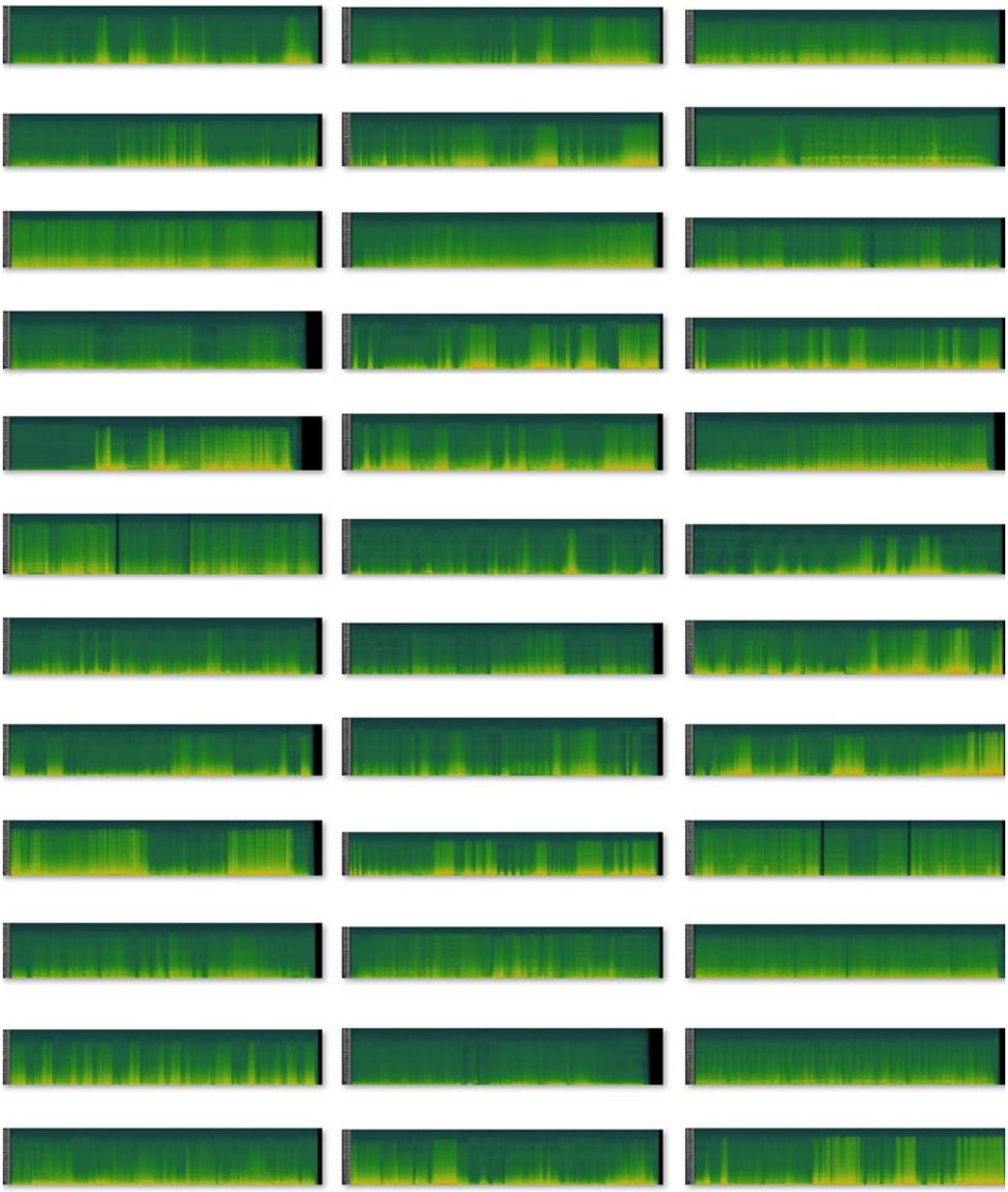


Figure B.1. Spectrogram views of classical music pieces

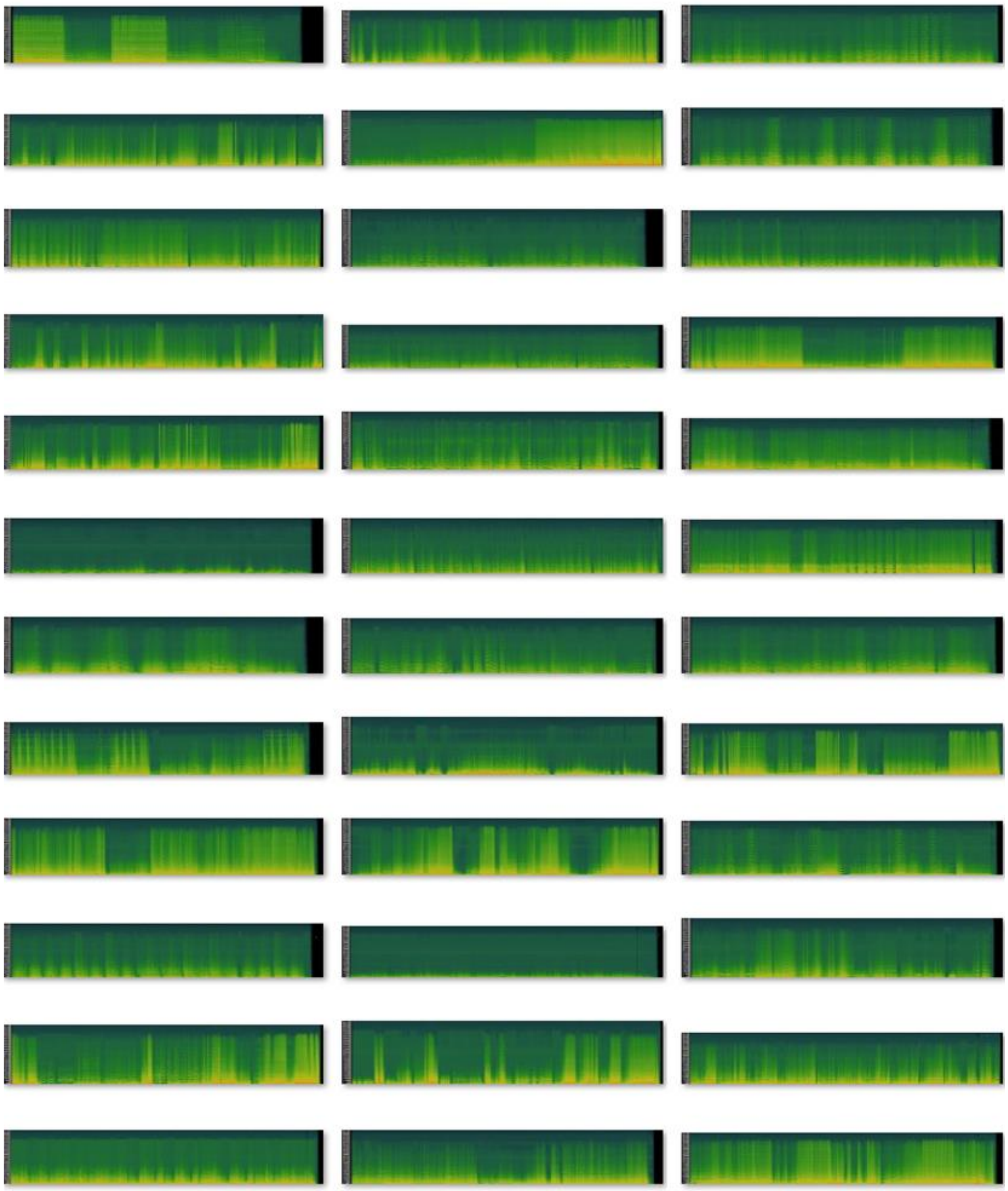


Figure B.2. Spectrogram views of classical music pieces, continued

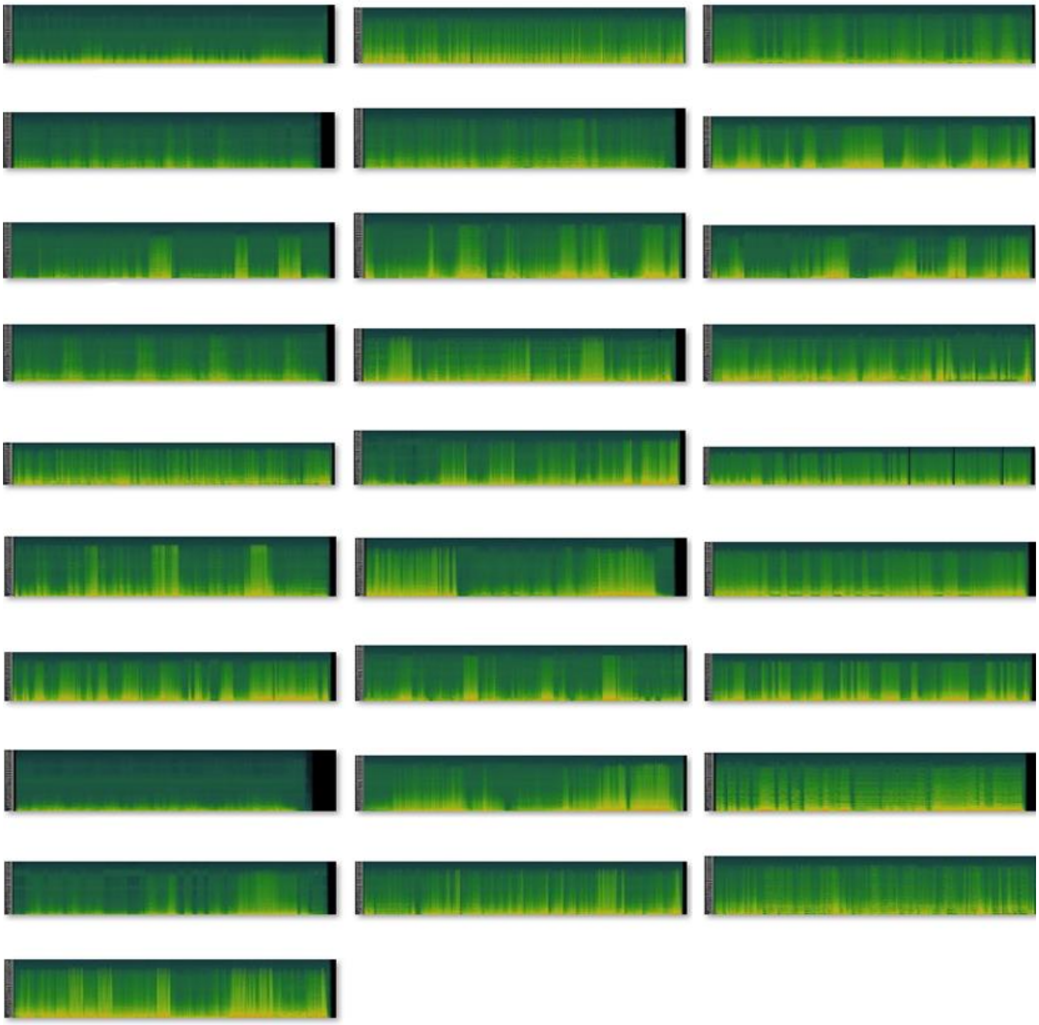


Figure B.3. Spectrogram views of classical music pieces, continued

Opera

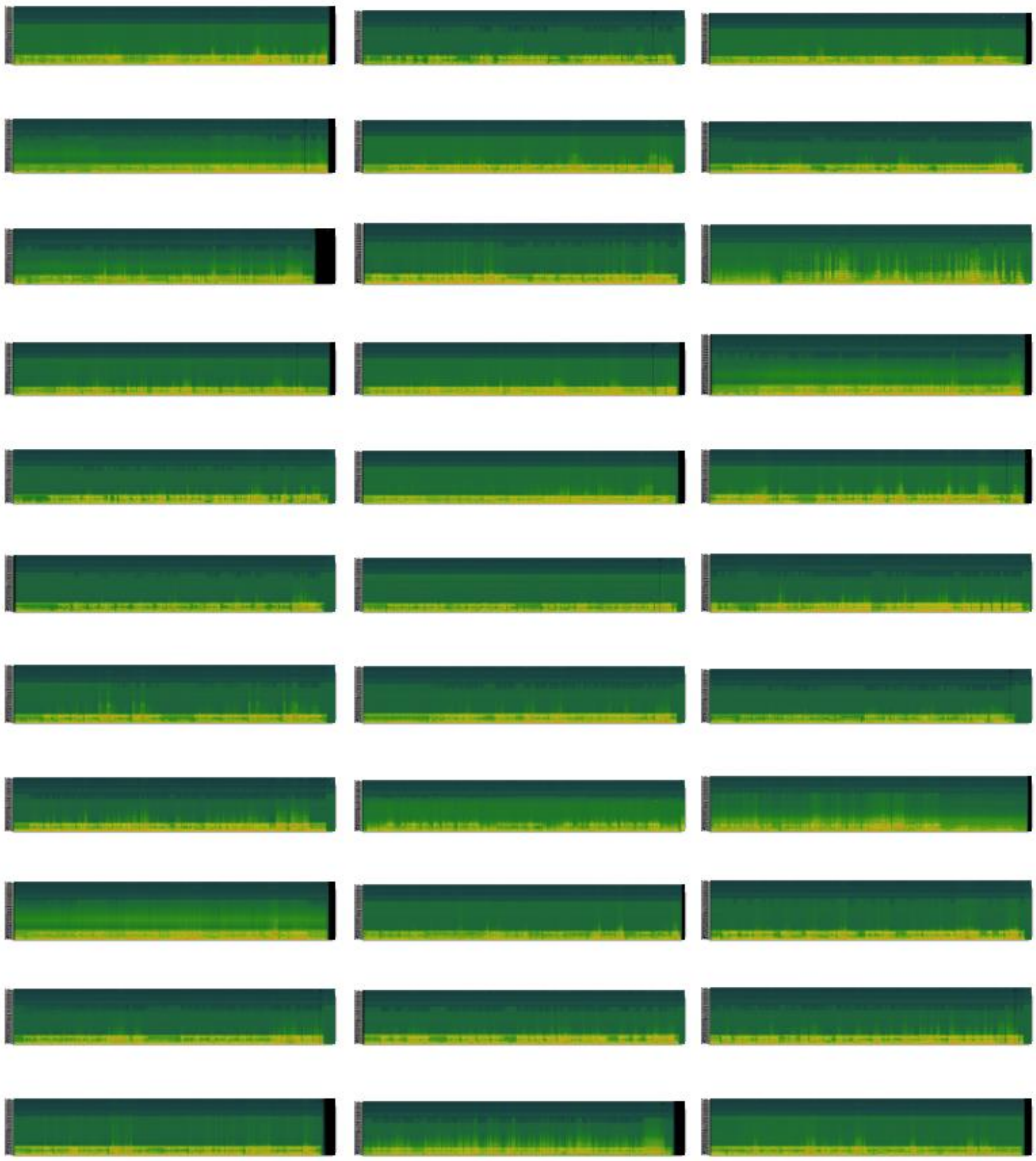


Figure B.4. Spectrogram views of opera pieces

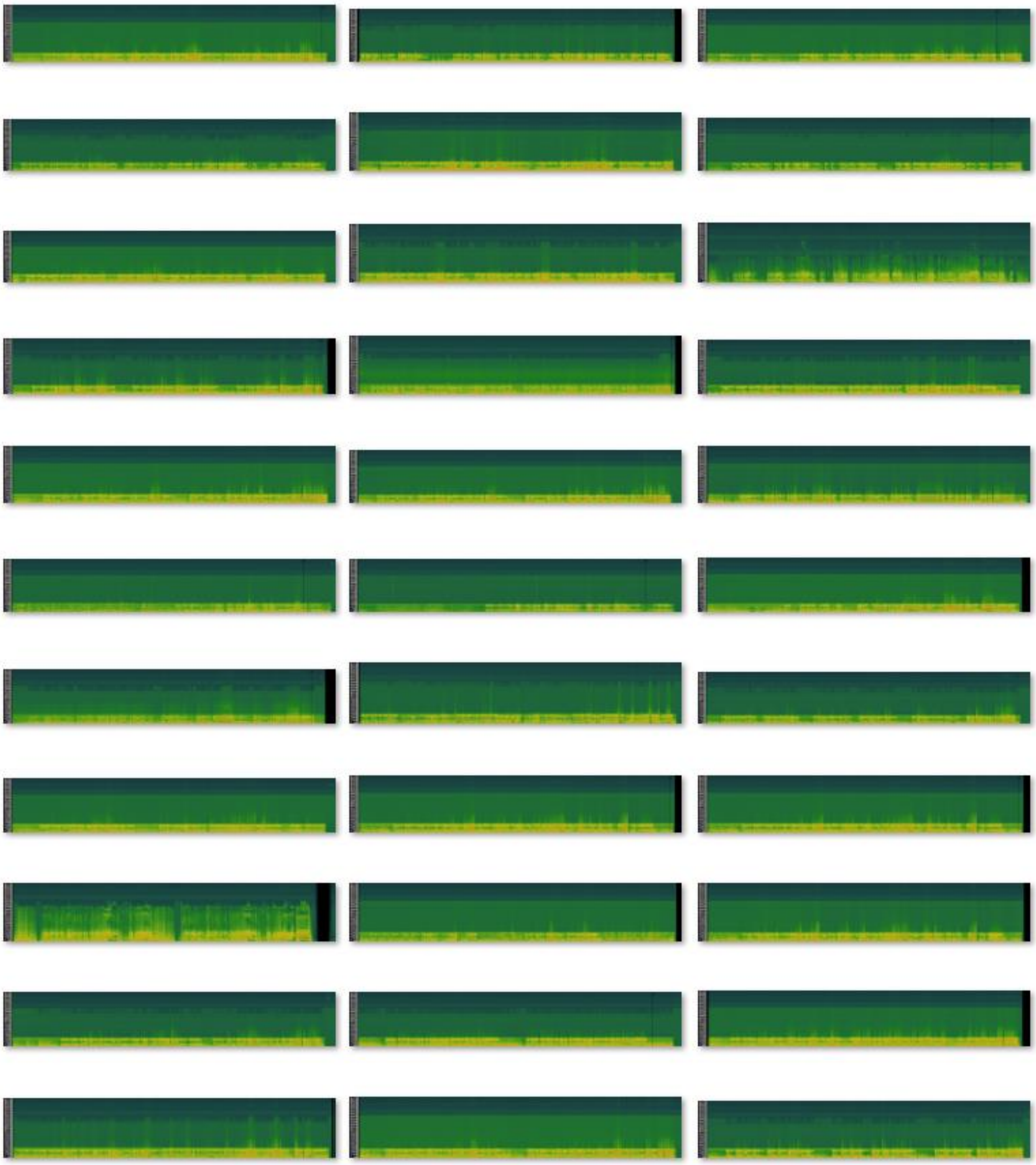


Figure B.5. Spectrogram views of opera pieces, continued

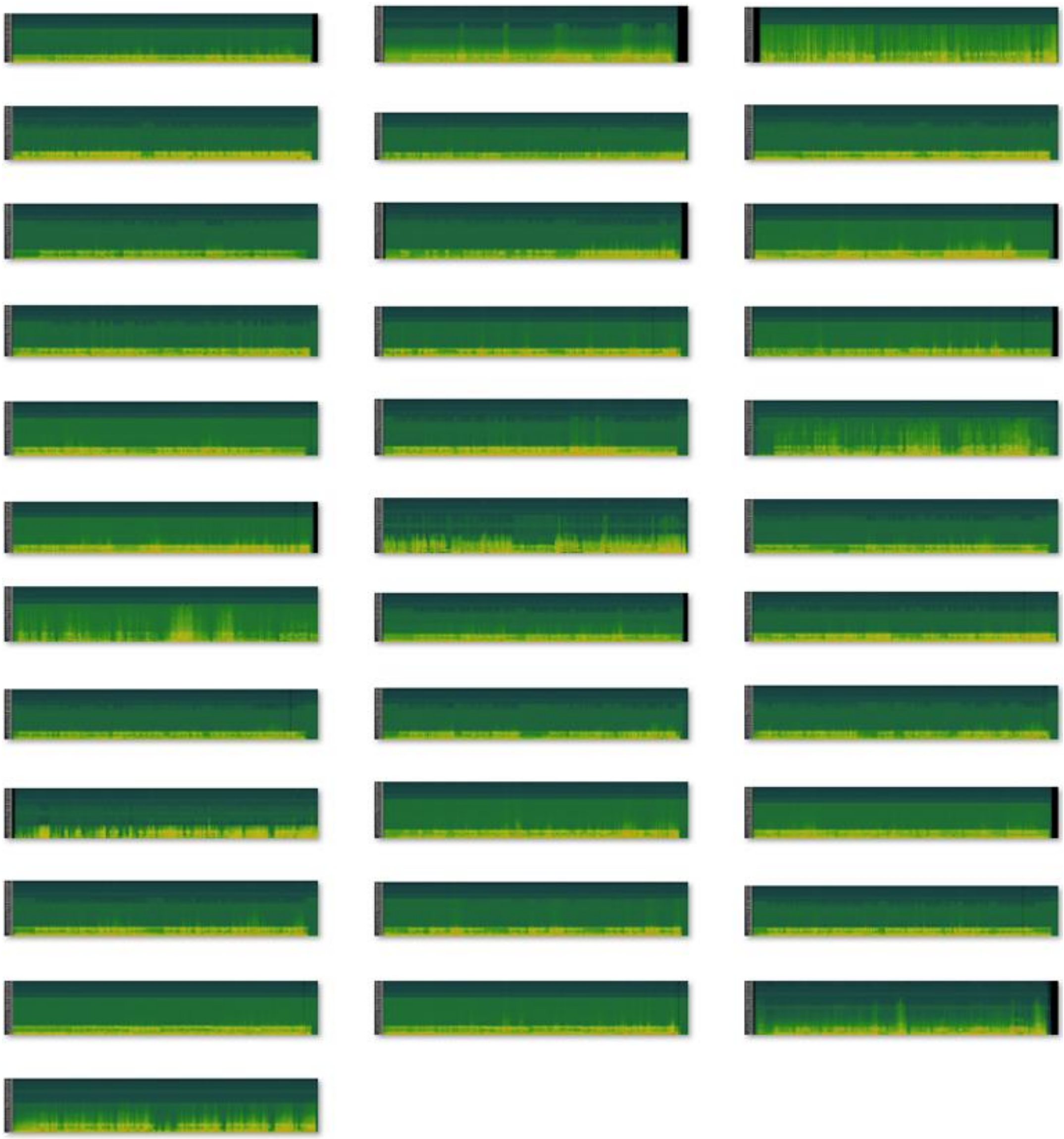


Figure B.6. Spectrogram views of opera pieces, continued

Turkish Classical Music

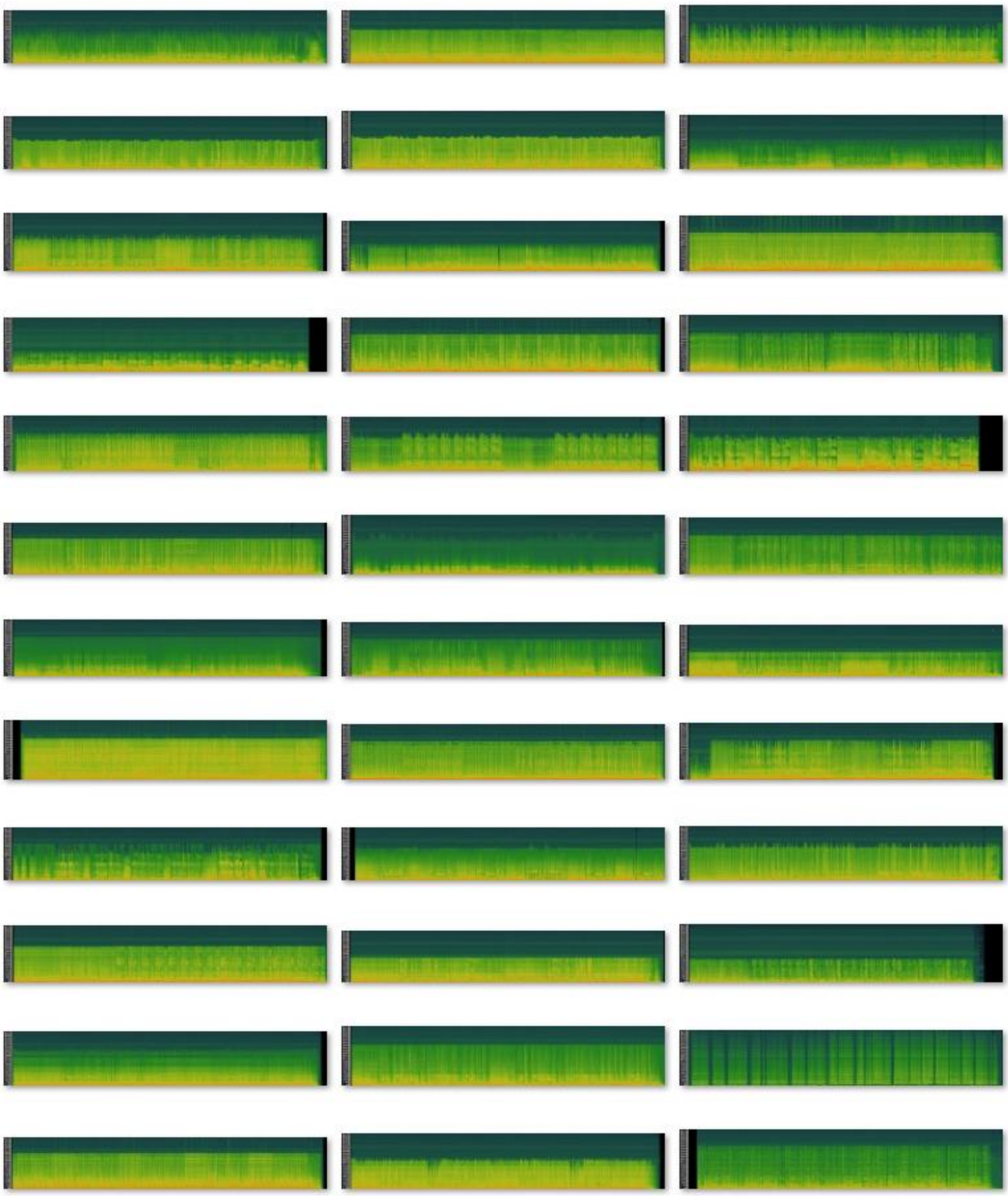


Figure B.7. Spectrogram views of Turkish classical music pieces

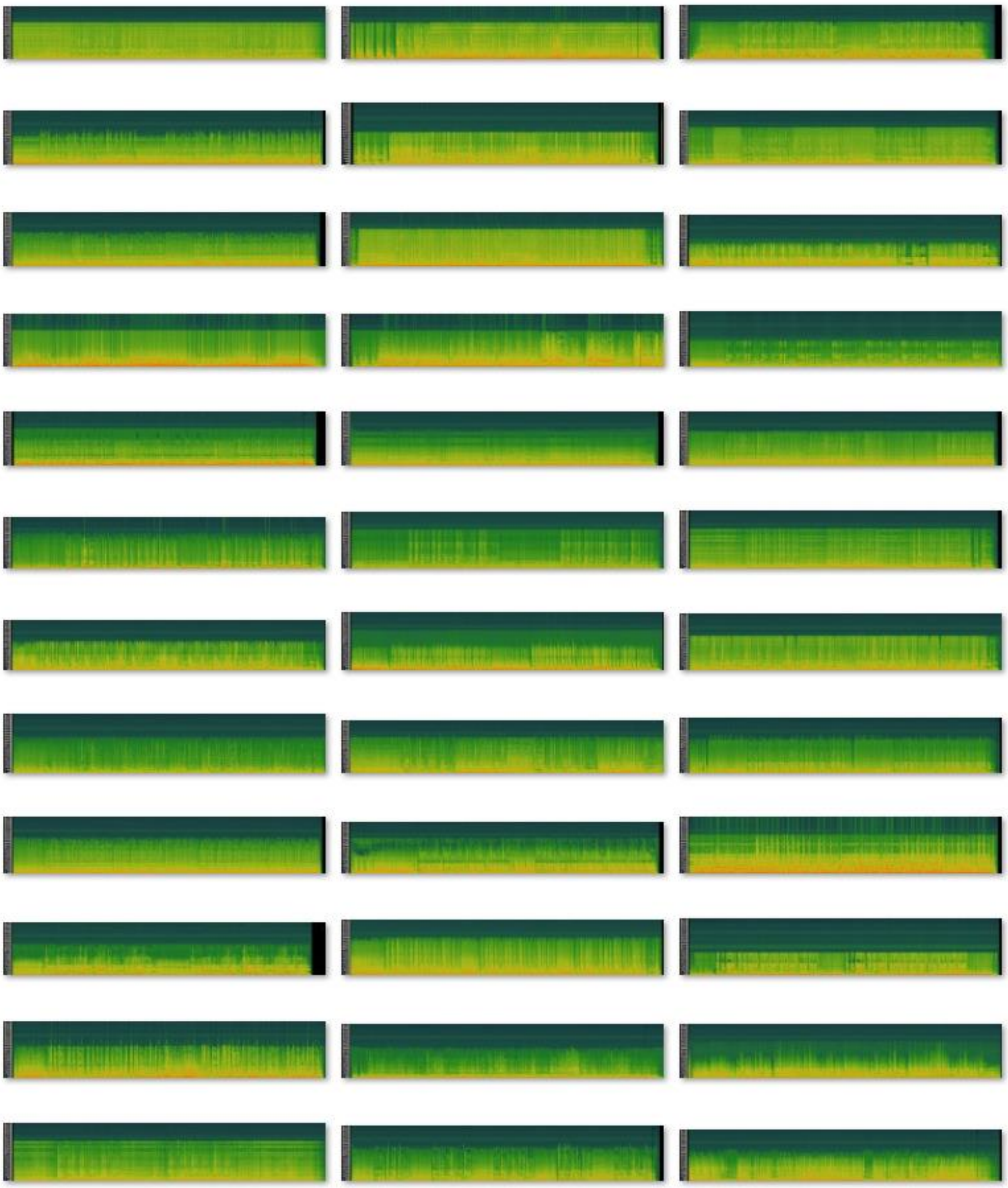


Figure B.8. Spectrogram views of Turkish classical music pieces, continued

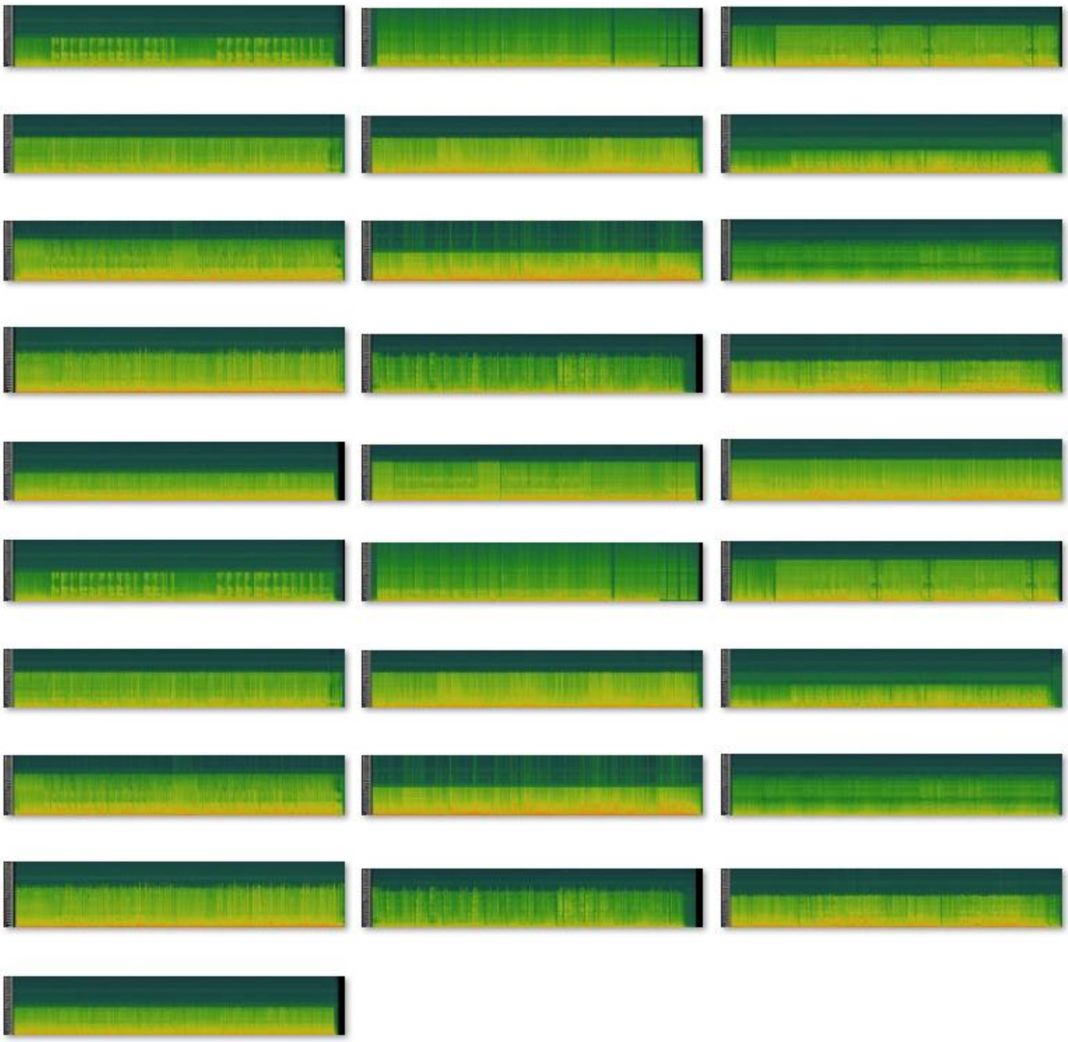


Figure B.9. Spectrogram views of Turkish classical music pieces, continued

C. GRID RESPONSES OF PERFORMANCE HALLS

Ankara Opera House

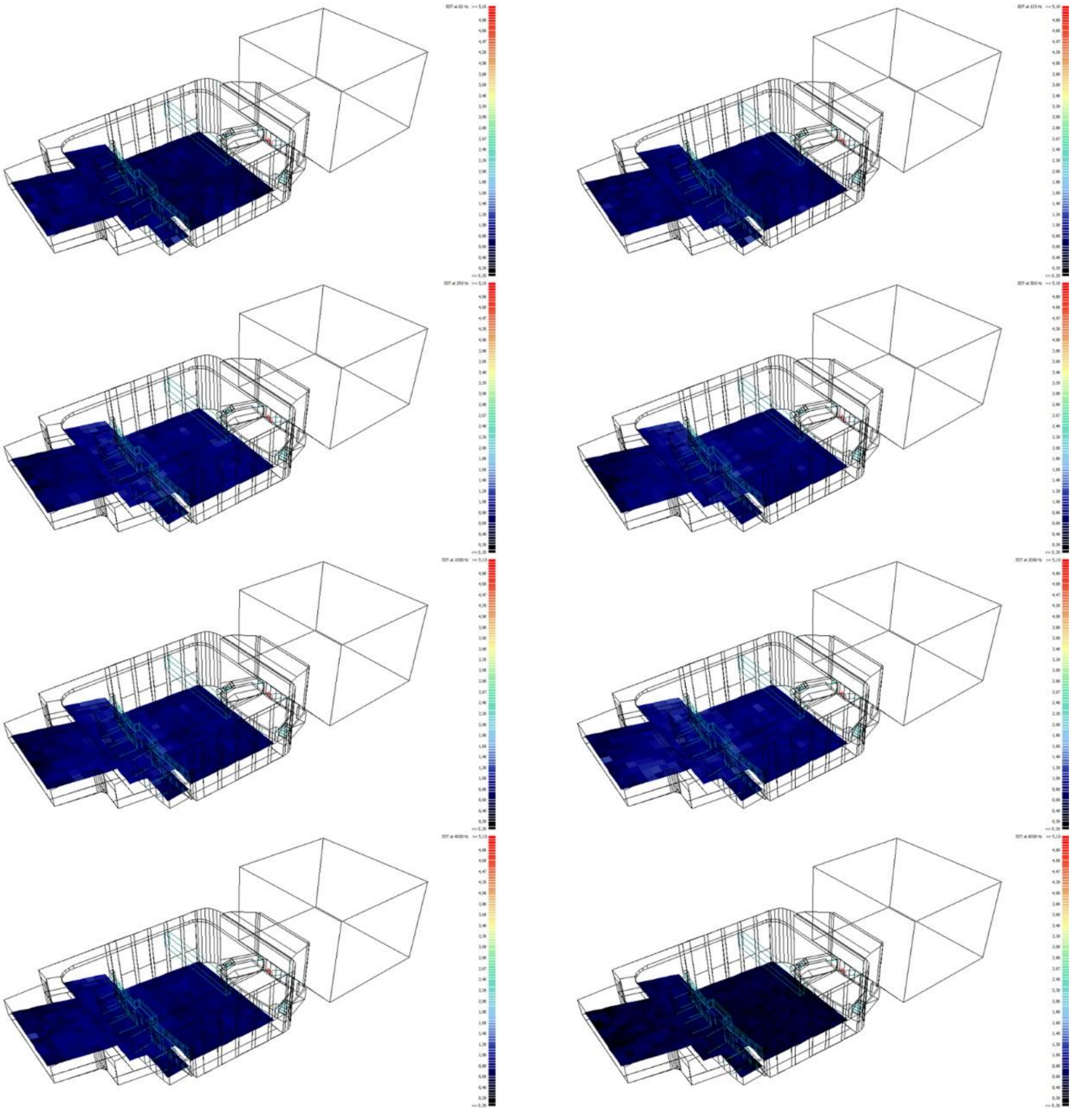


Figure C.1. EDT values in octave bands for Ankara Opera House

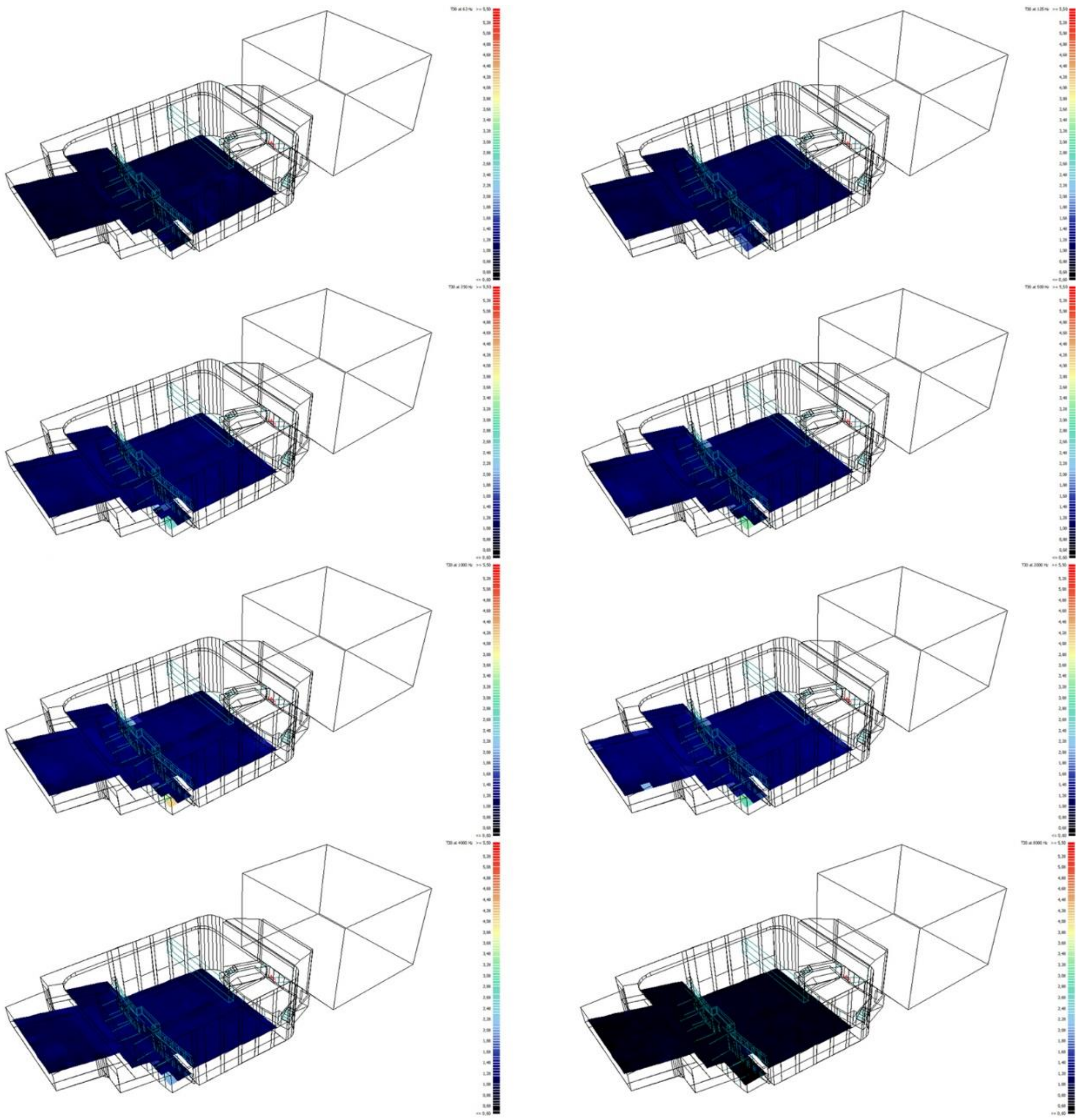


Figure C.2. T30 values in octave bands for Ankara Opera House

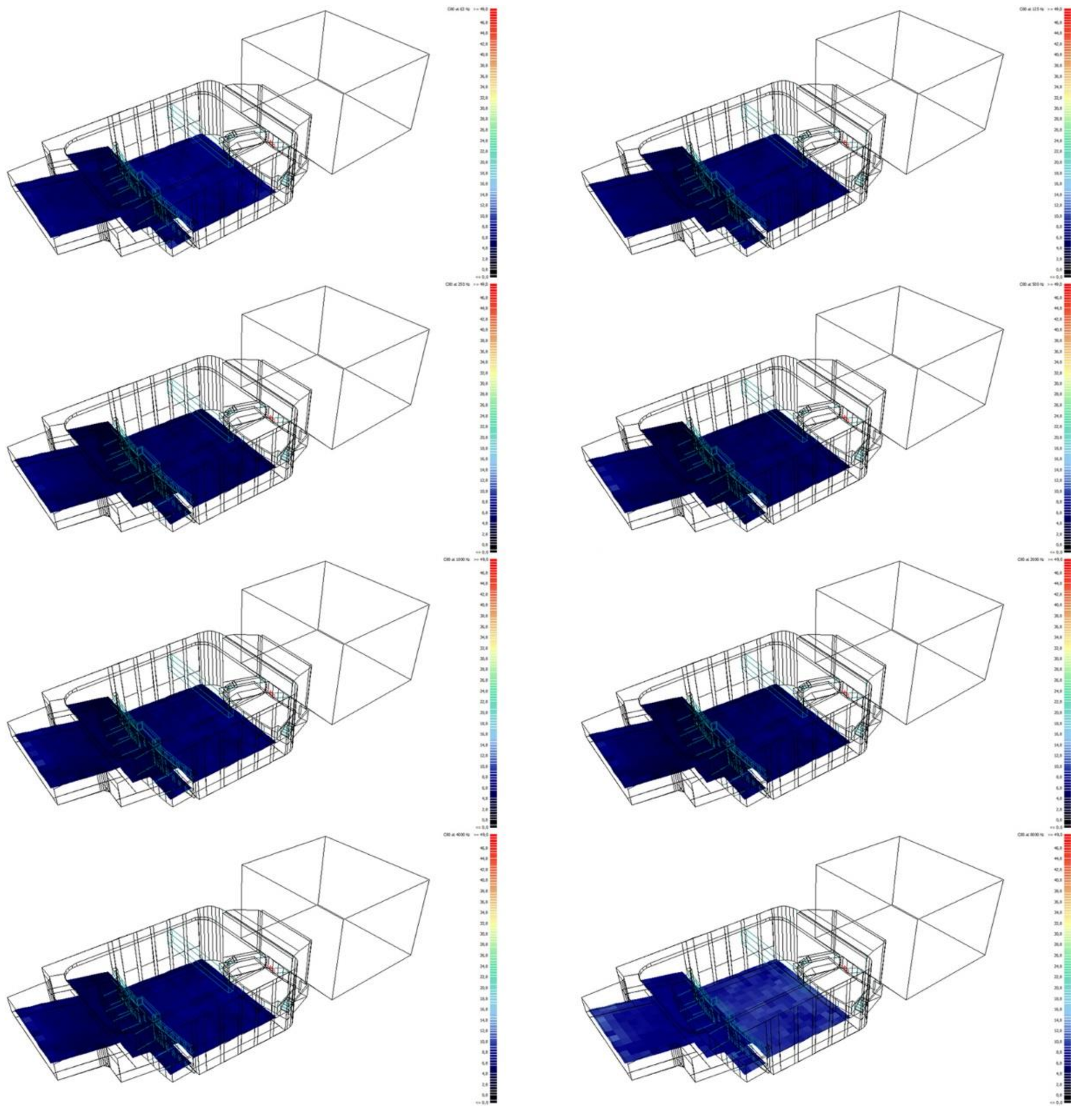


Figure C.3. C80 values in octave bands for Ankara Opera House

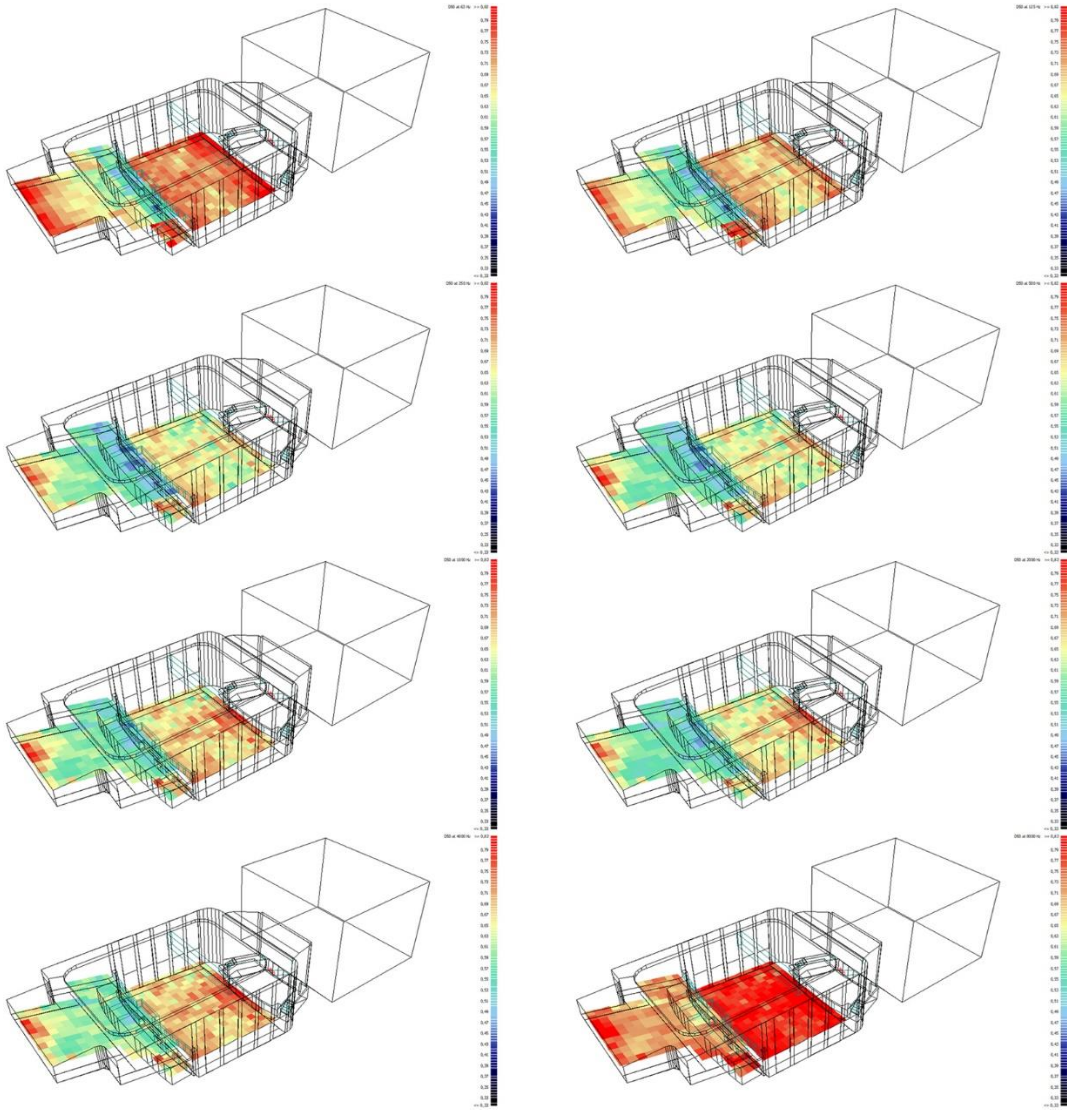


Figure C.4. D50 values in octave bands for Ankara Opera House

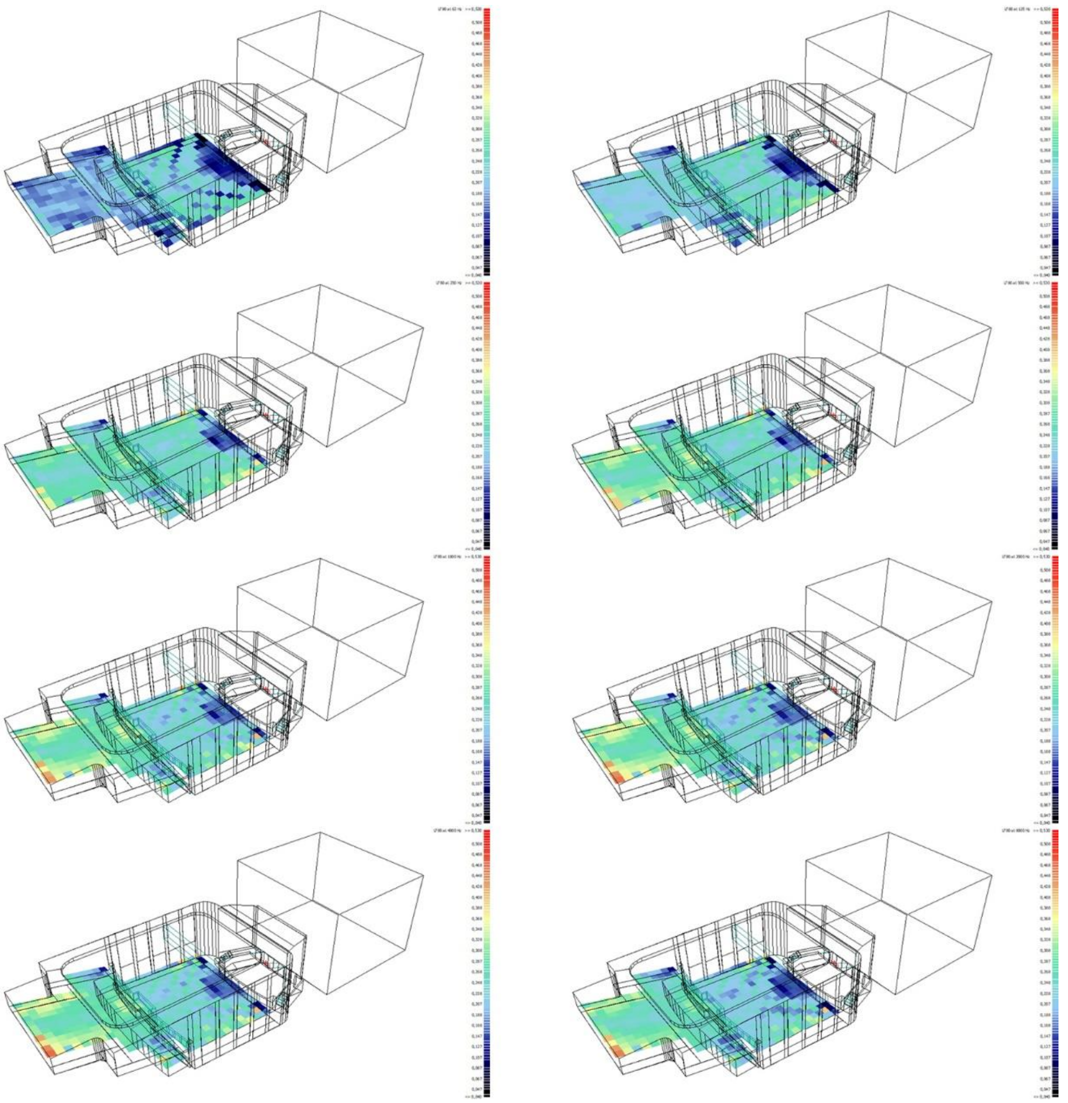


Figure C.5. LF80 values in octave bands for Ankara Opera House

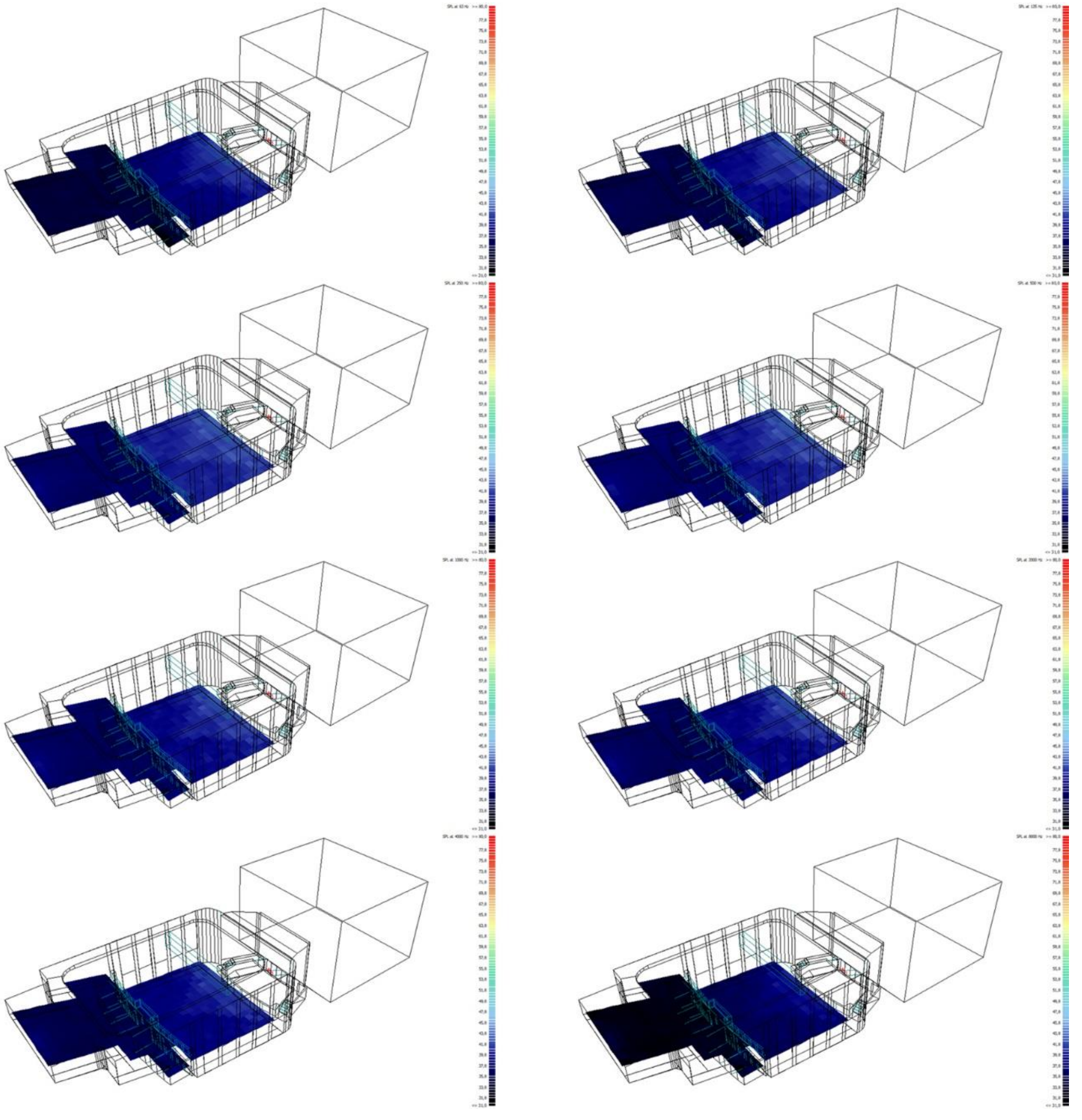


Figure C.6. SPL values in octave bands for Ankara Opera House

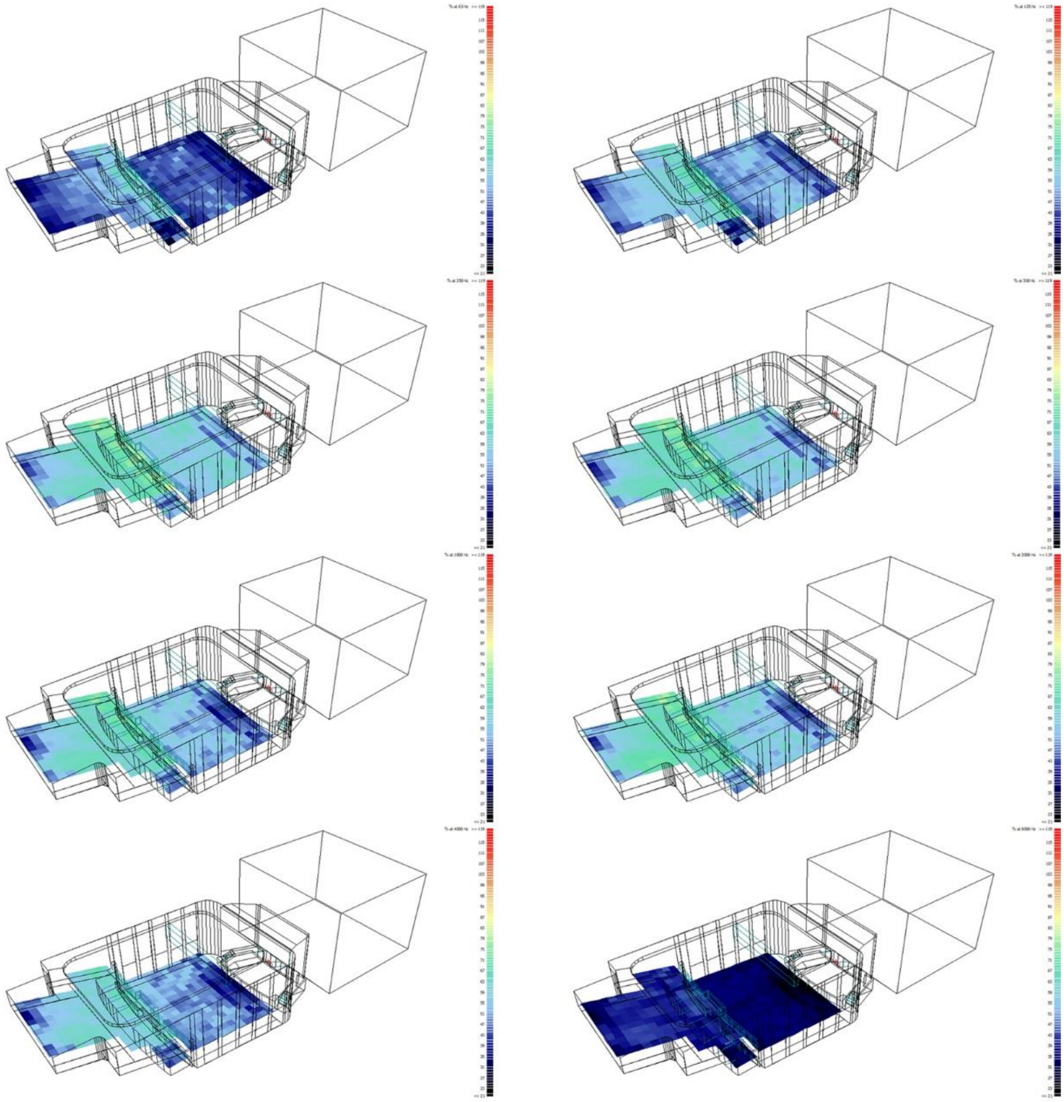


Figure C.7. Ts values in octave bands for Ankara Opera House

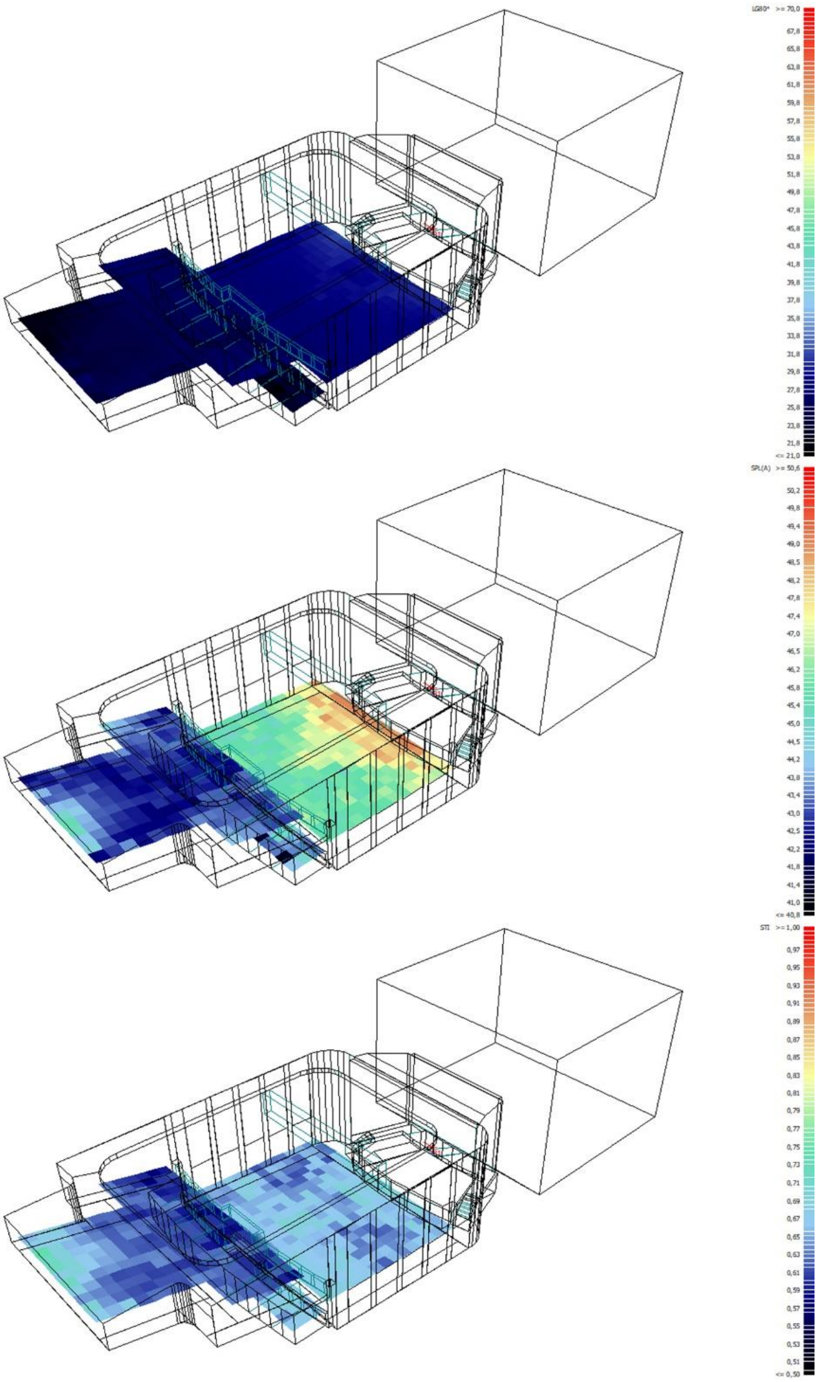


Figure C.8. LG80, SPL(A) and STI values for Ankara Opera House

ESMMMO Conference Hall

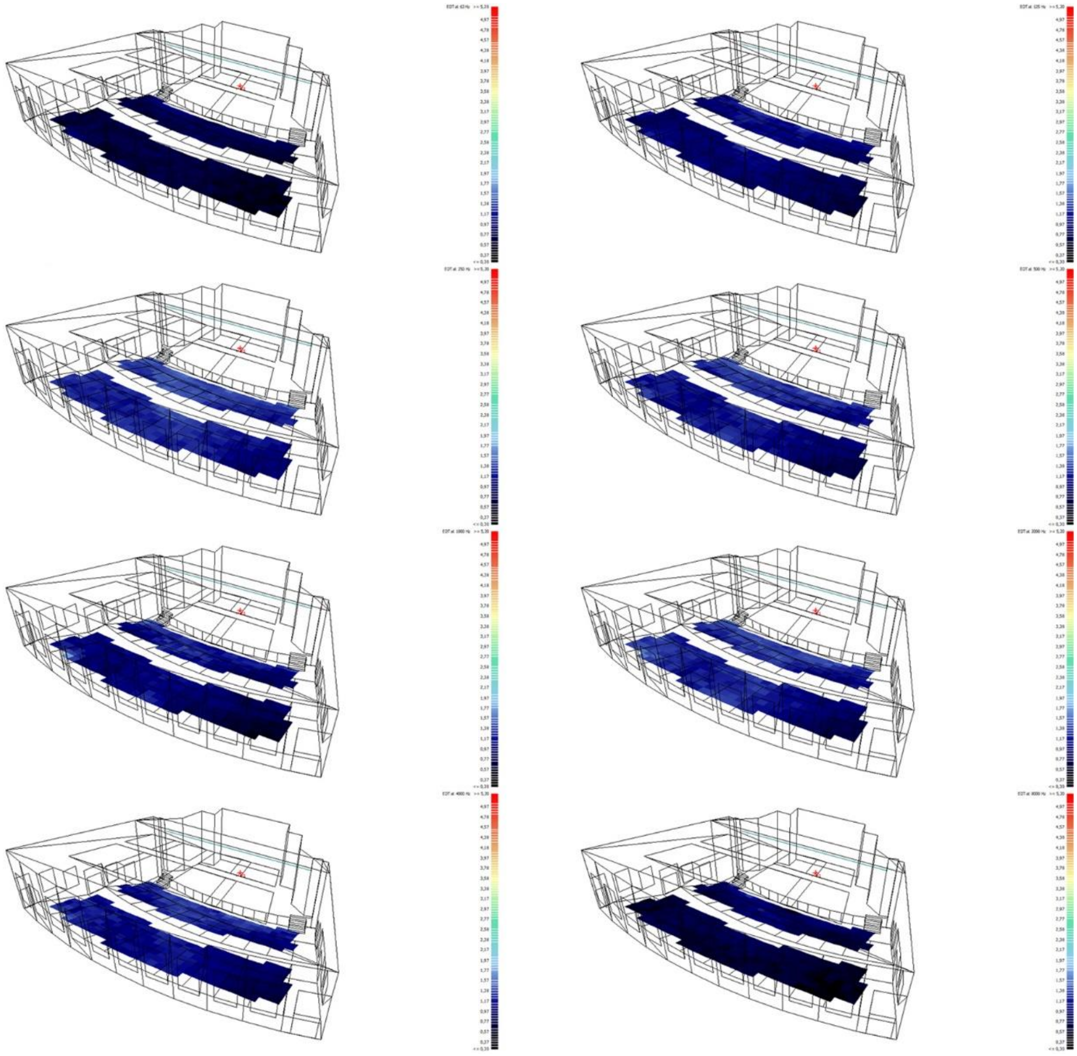


Figure C.9. EDT values in octave bands for ESMMMO Conference Hall

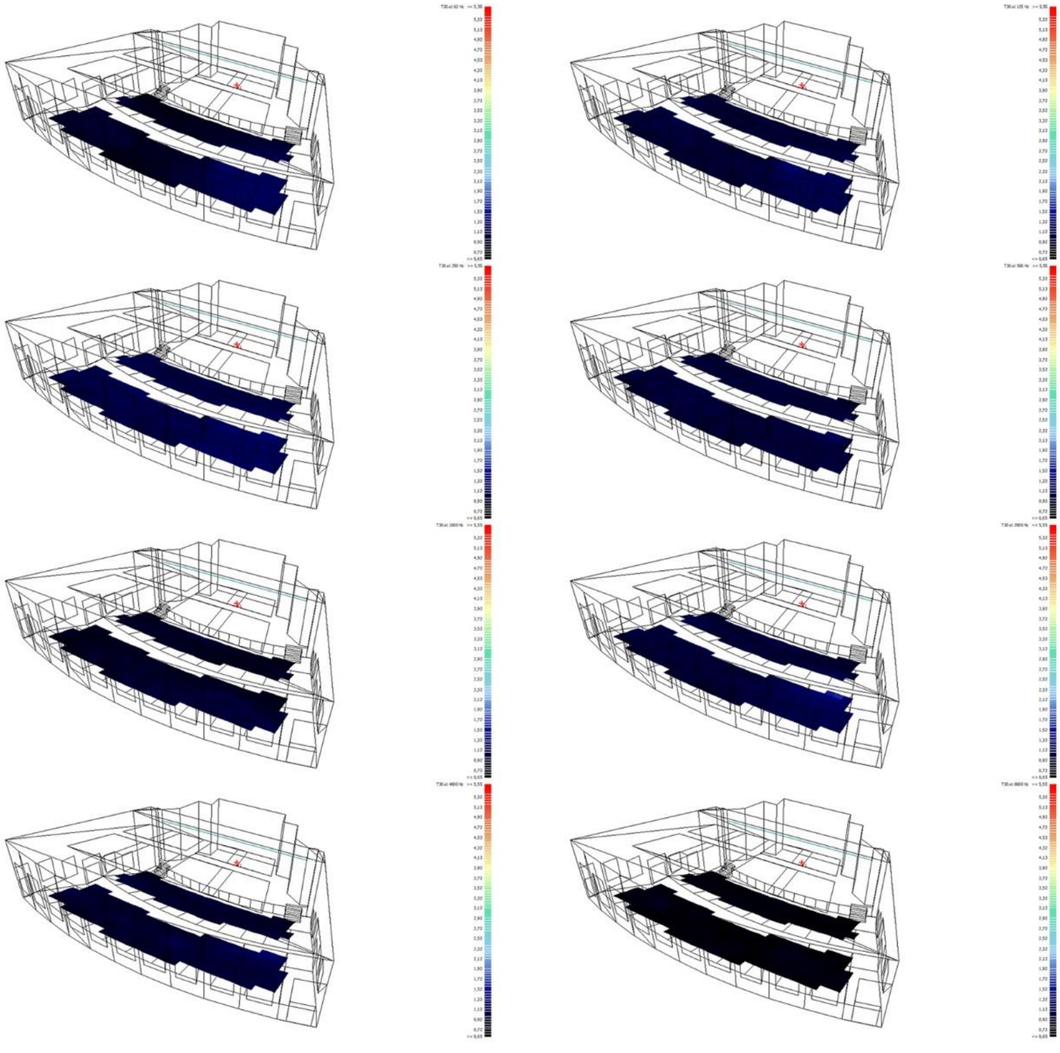


Figure C.10. T30 values in octave bands for ESMMMO Conference Hall

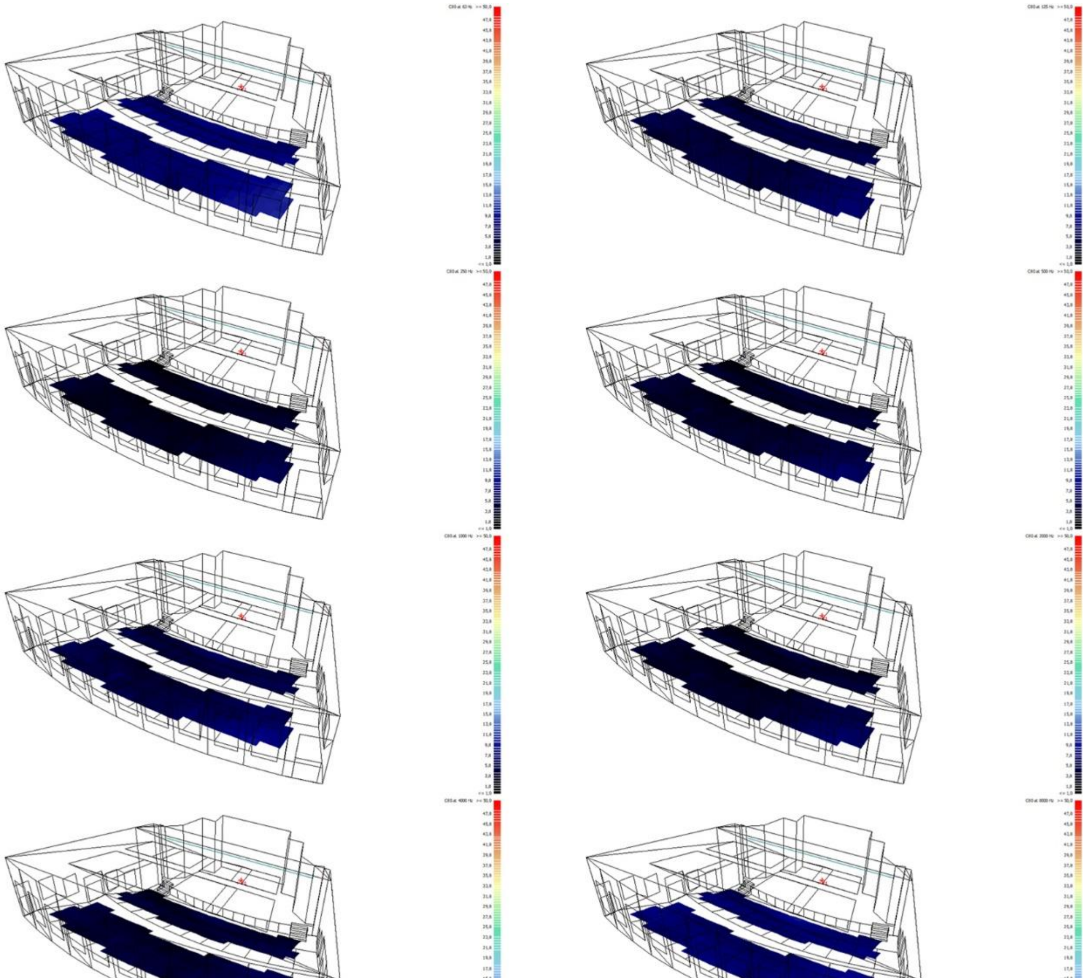


Figure C.11. C80 values in octave bands for ESMMMO Conference Hall

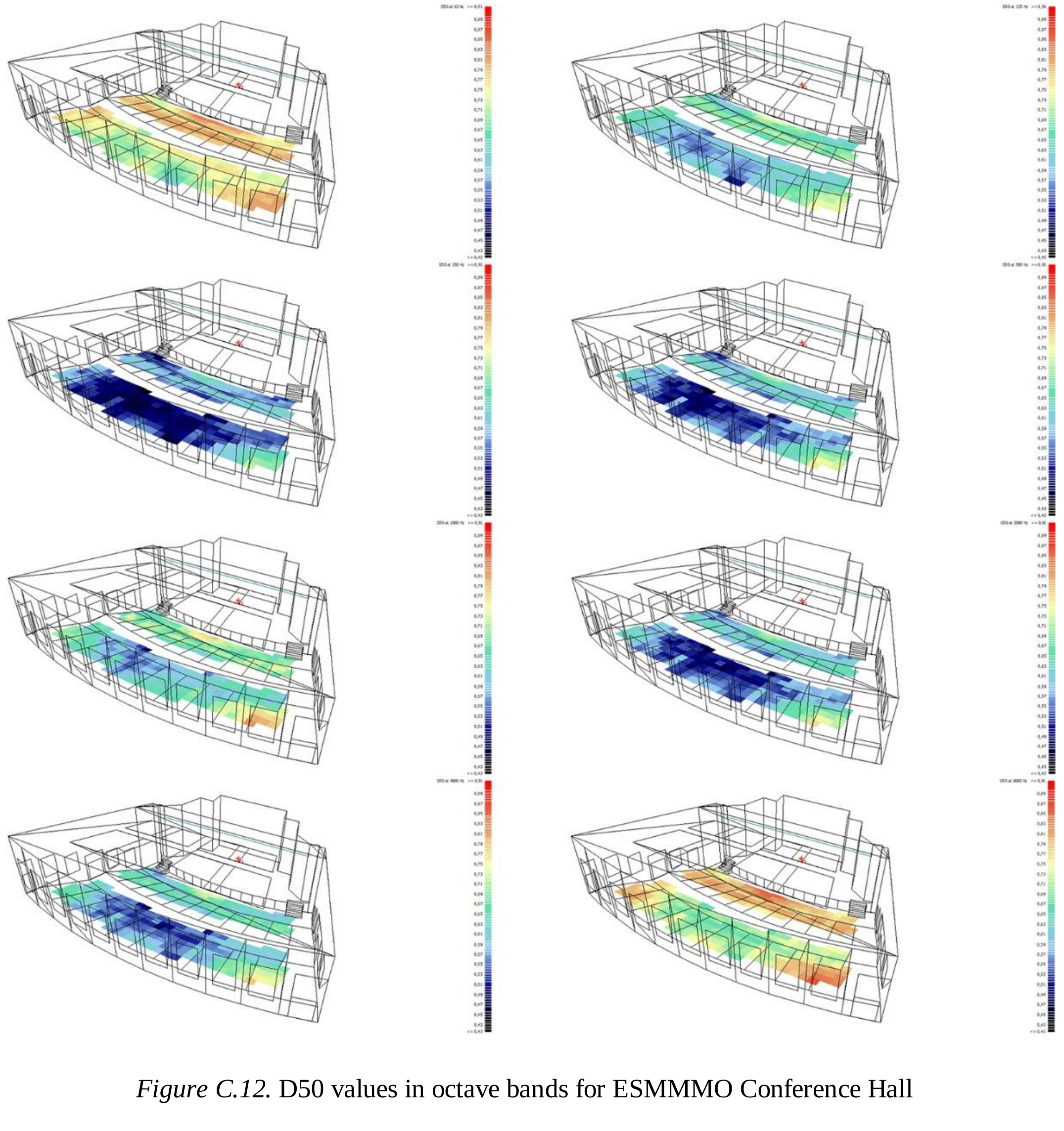


Figure C.12. D50 values in octave bands for ESMMMO Conference Hall

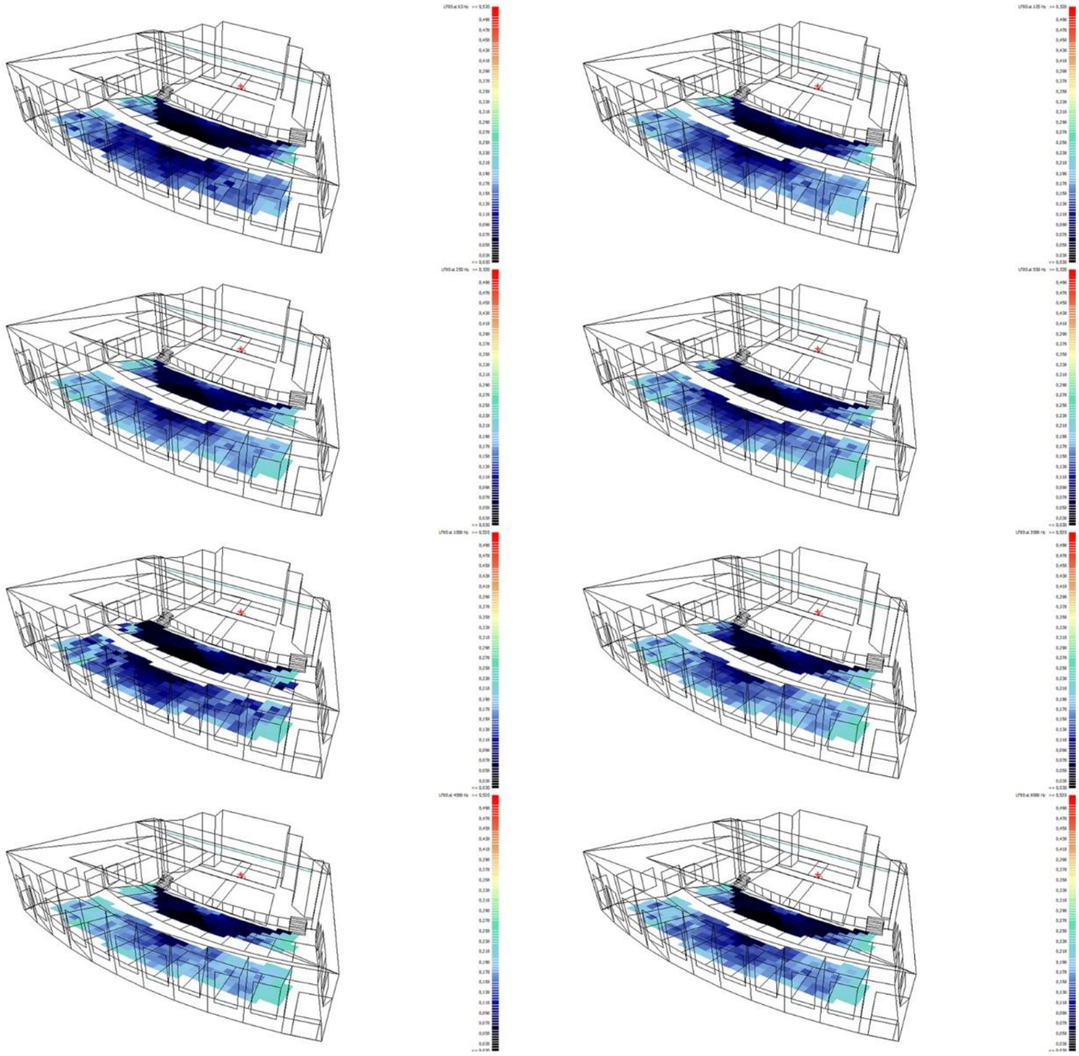


Figure C.13. LF80 values in octave bands for ESMMMO Conference Hall

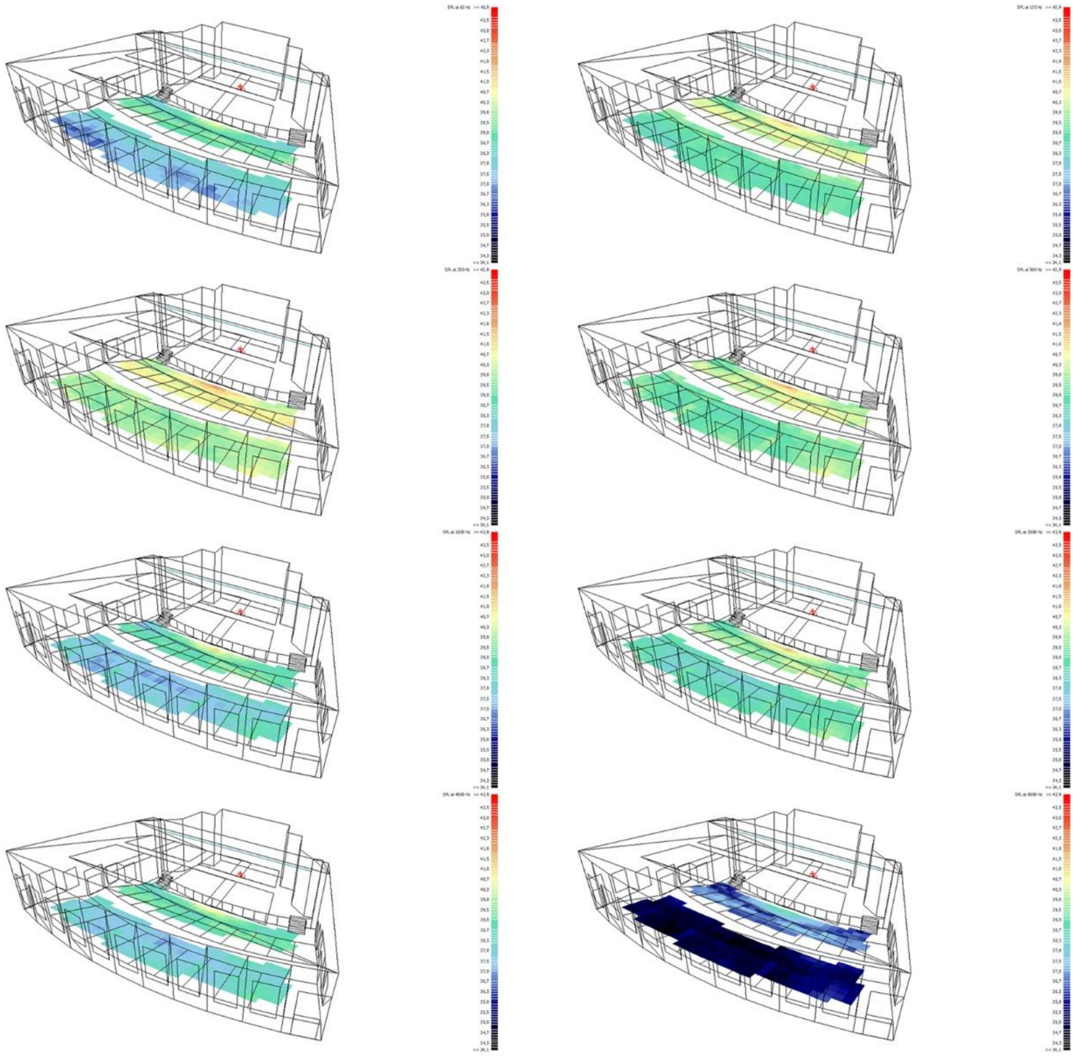


Figure C.14. SPL values in octave bands for ESMMMO Conference Hall

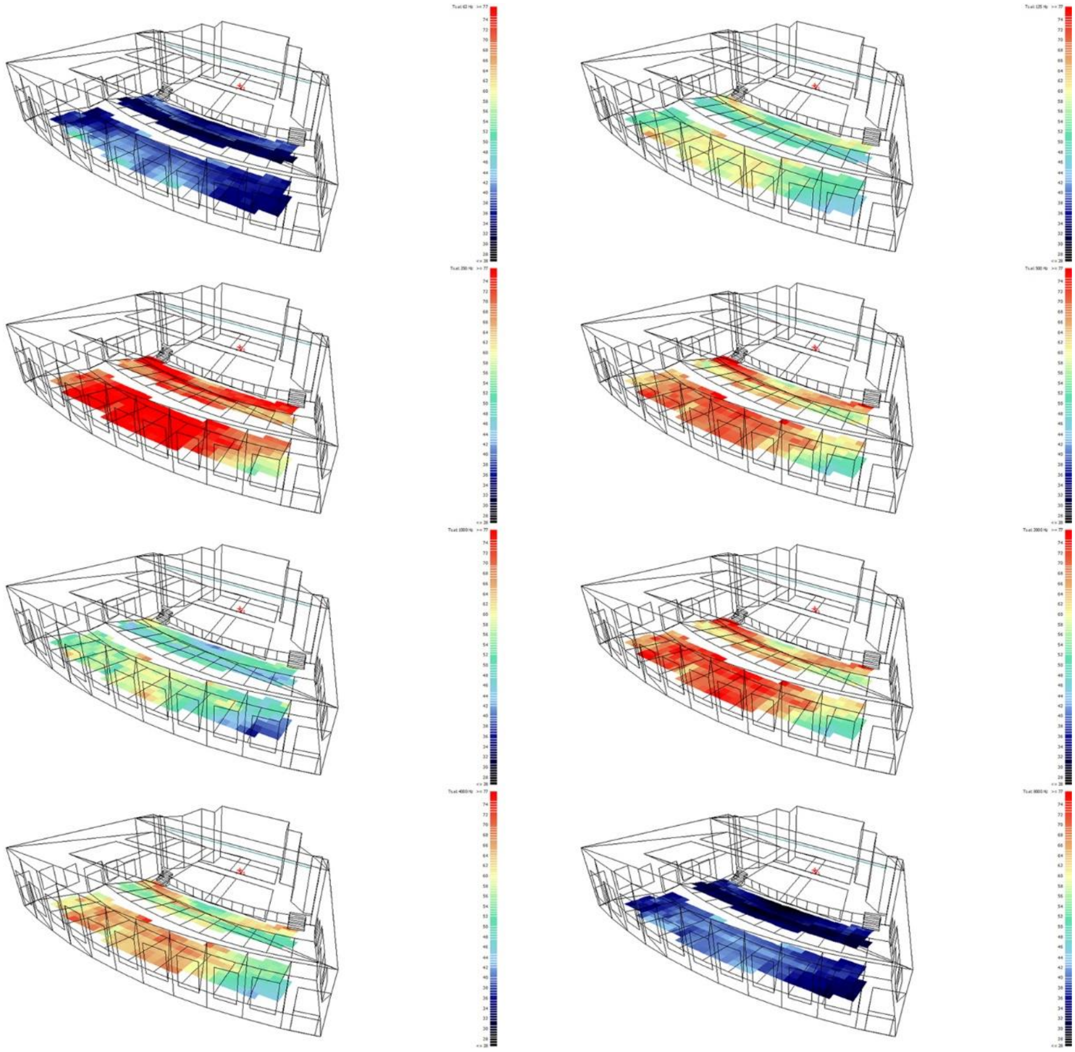


Figure C.15. Ts values in octave bands for ESMMMO Conference Hall

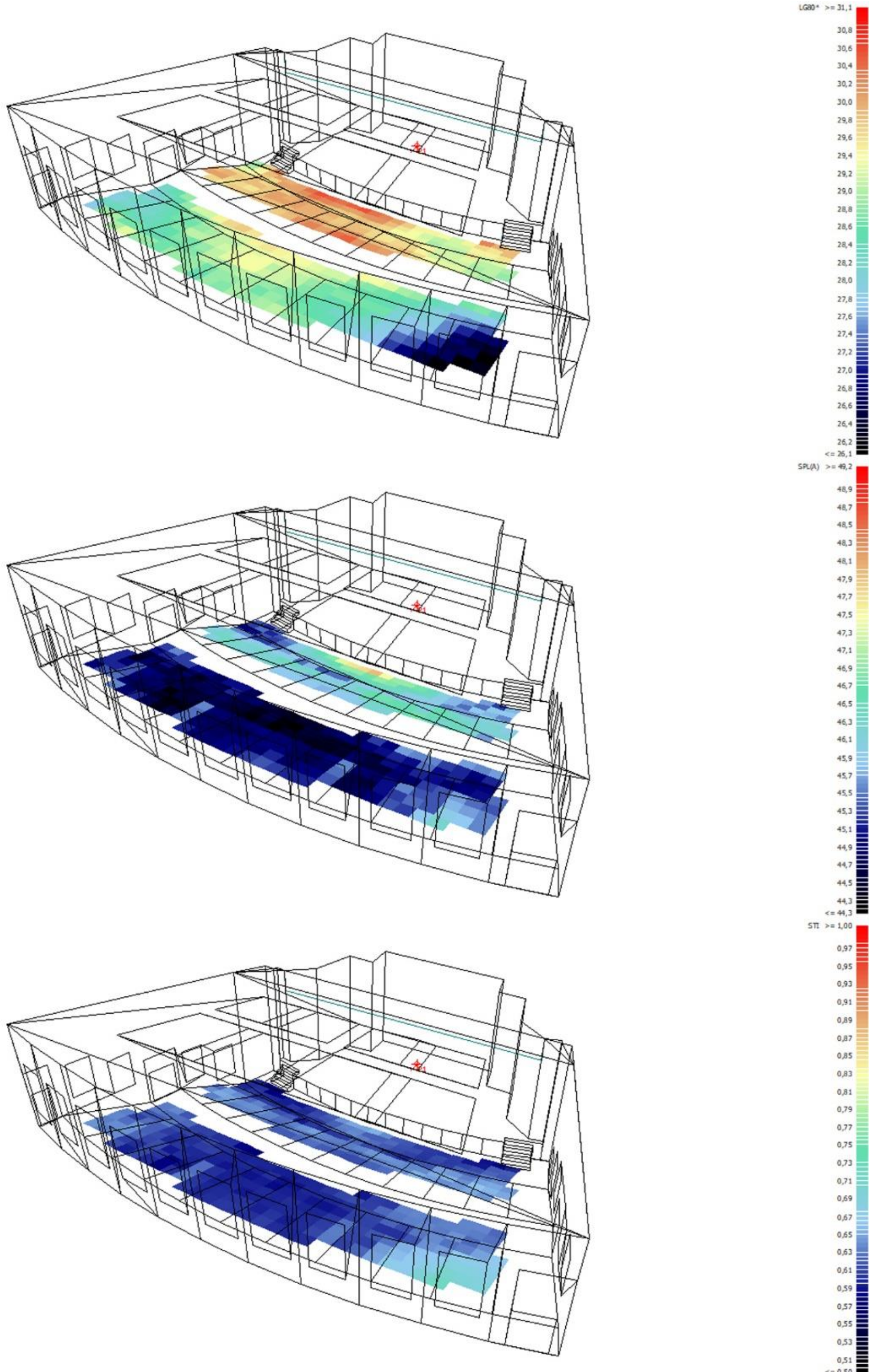


Figure C.16. LG80, SPL(A) and STI values for ESMMMO Conference Hall

Air Forces Headquarters

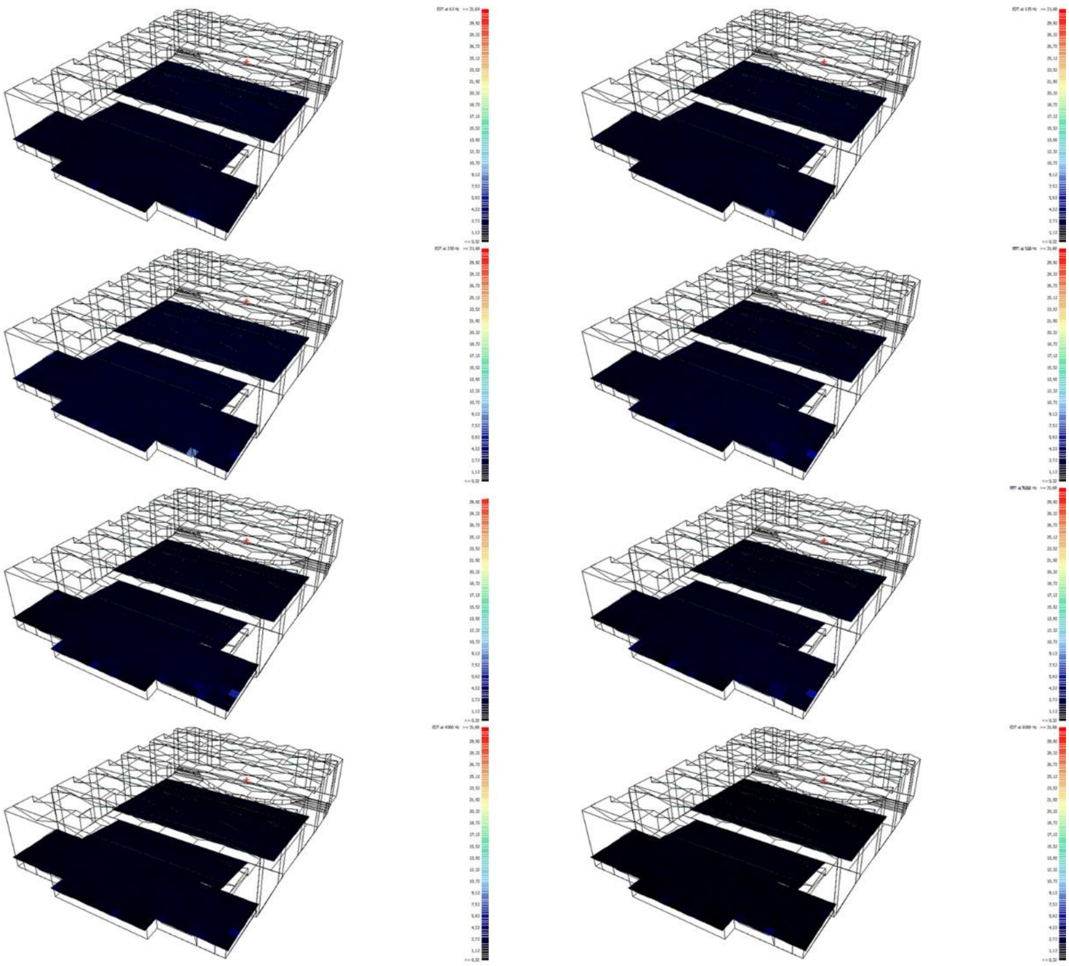


Figure C.17. EDT values in octave bands for Air Force HQ Conference Hall

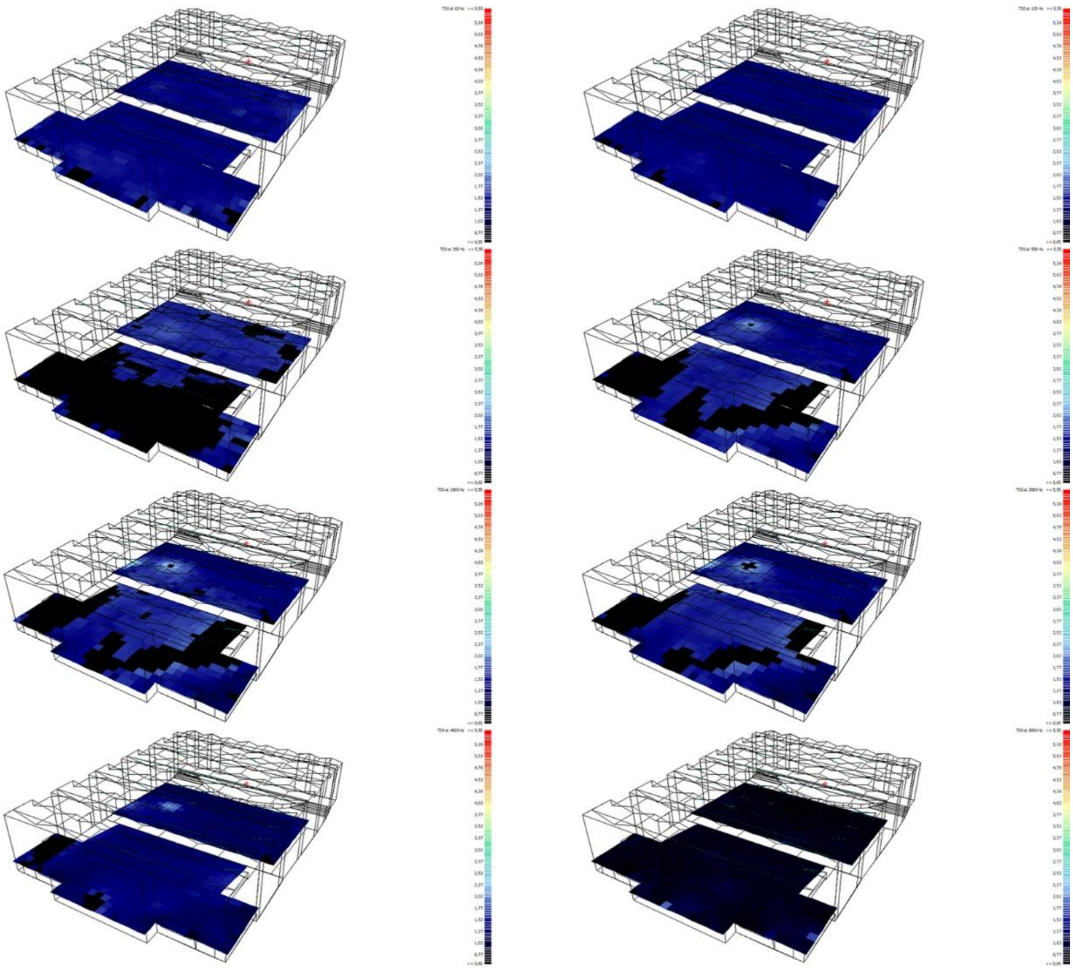


Figure C.18. T30 values in octave bands for Air Force HQ Conference Hall

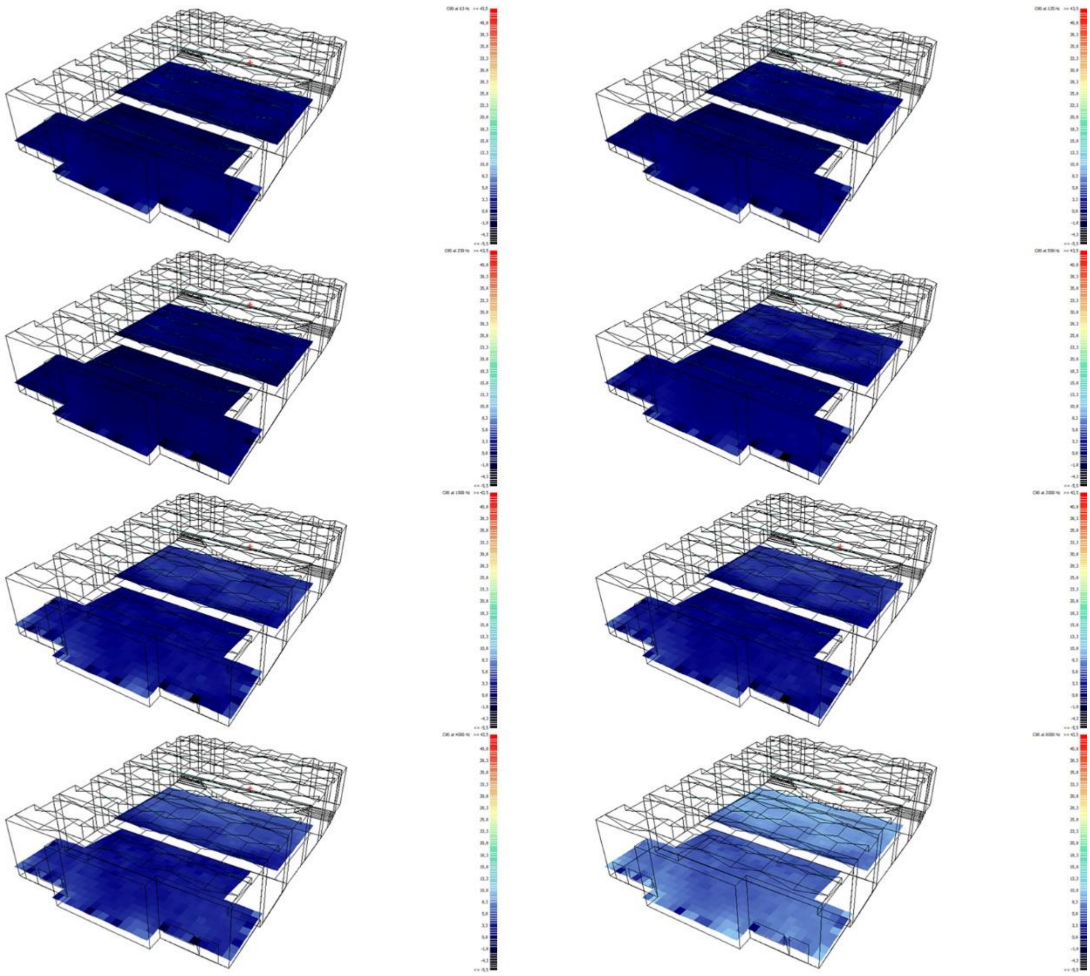


Figure C.19. C80 values in octave bands for Air Force HQ Conference Hall

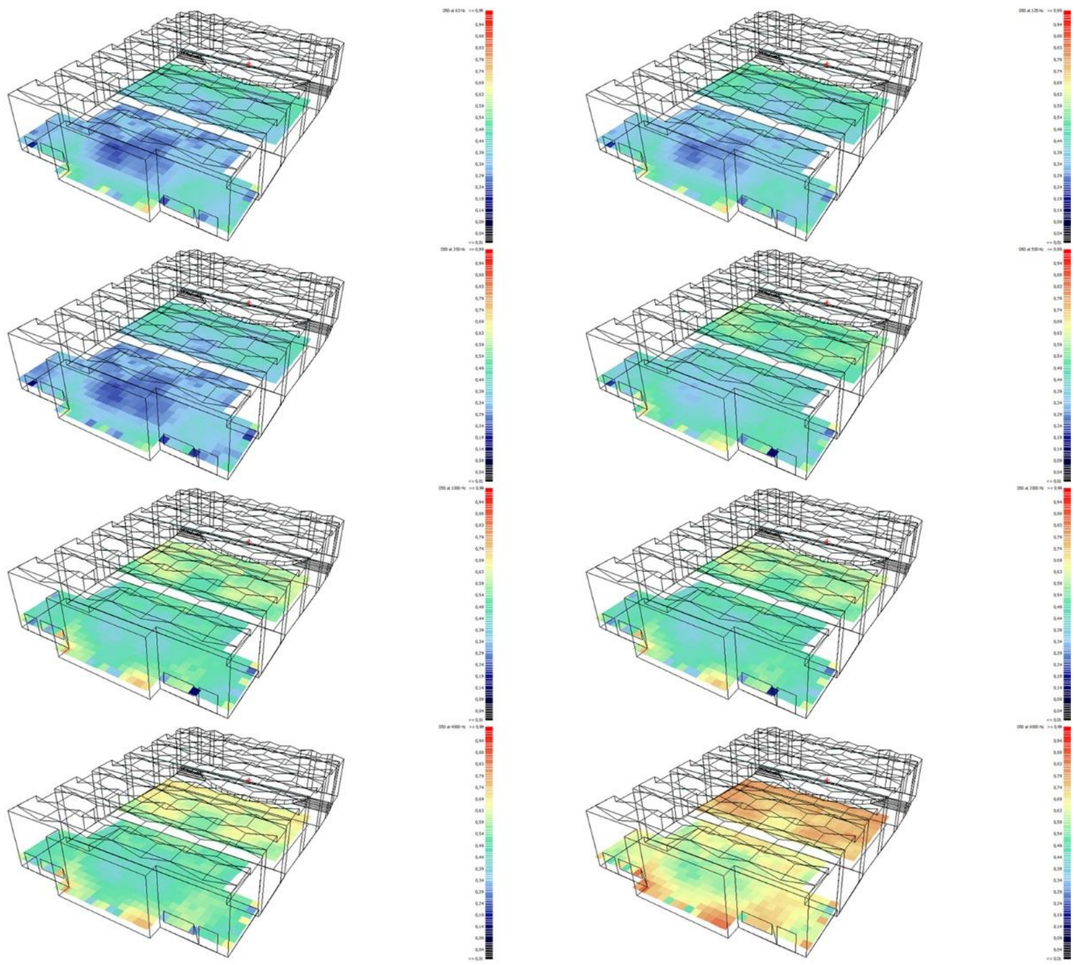


Figure C.20. D50 values in octave bands for Air Force HQ Conference Hall

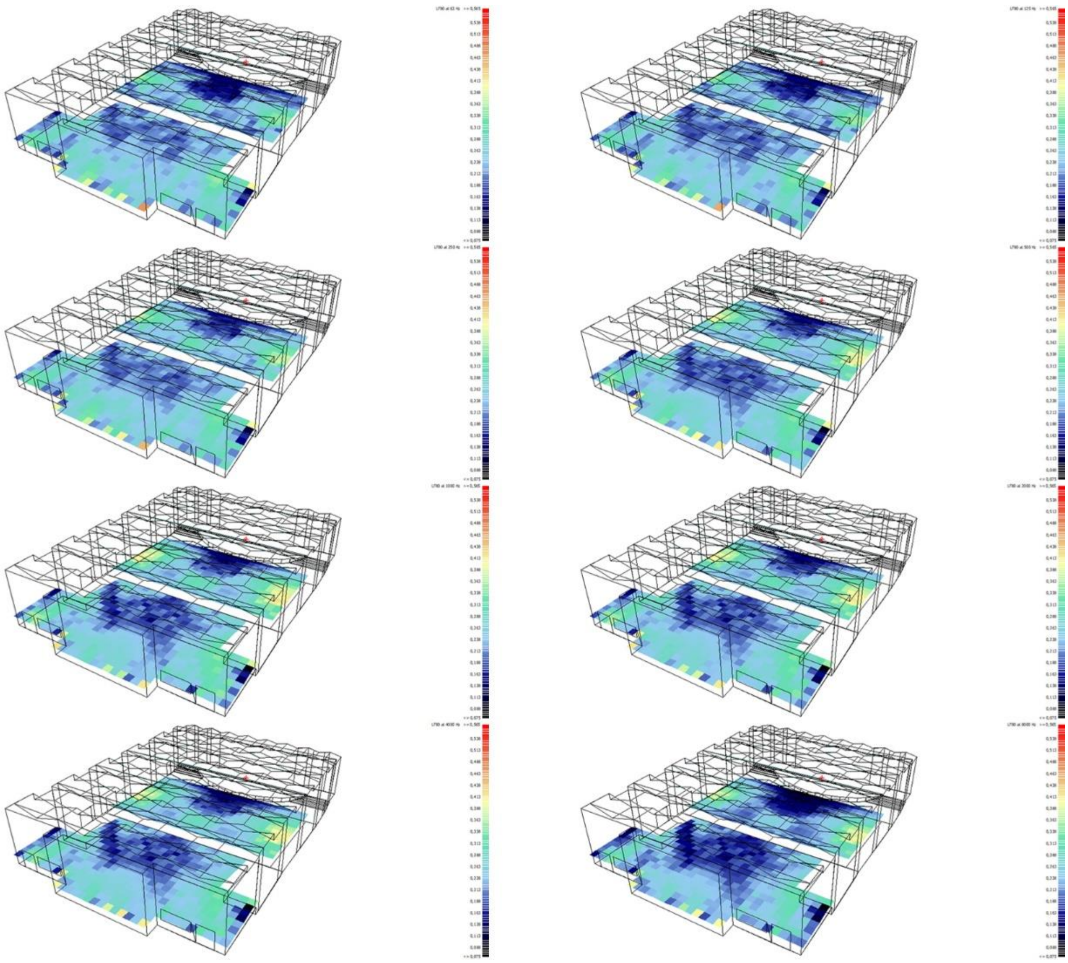


Figure C.21. LF80 values in octave bands for Air Force HQ Conference Hall

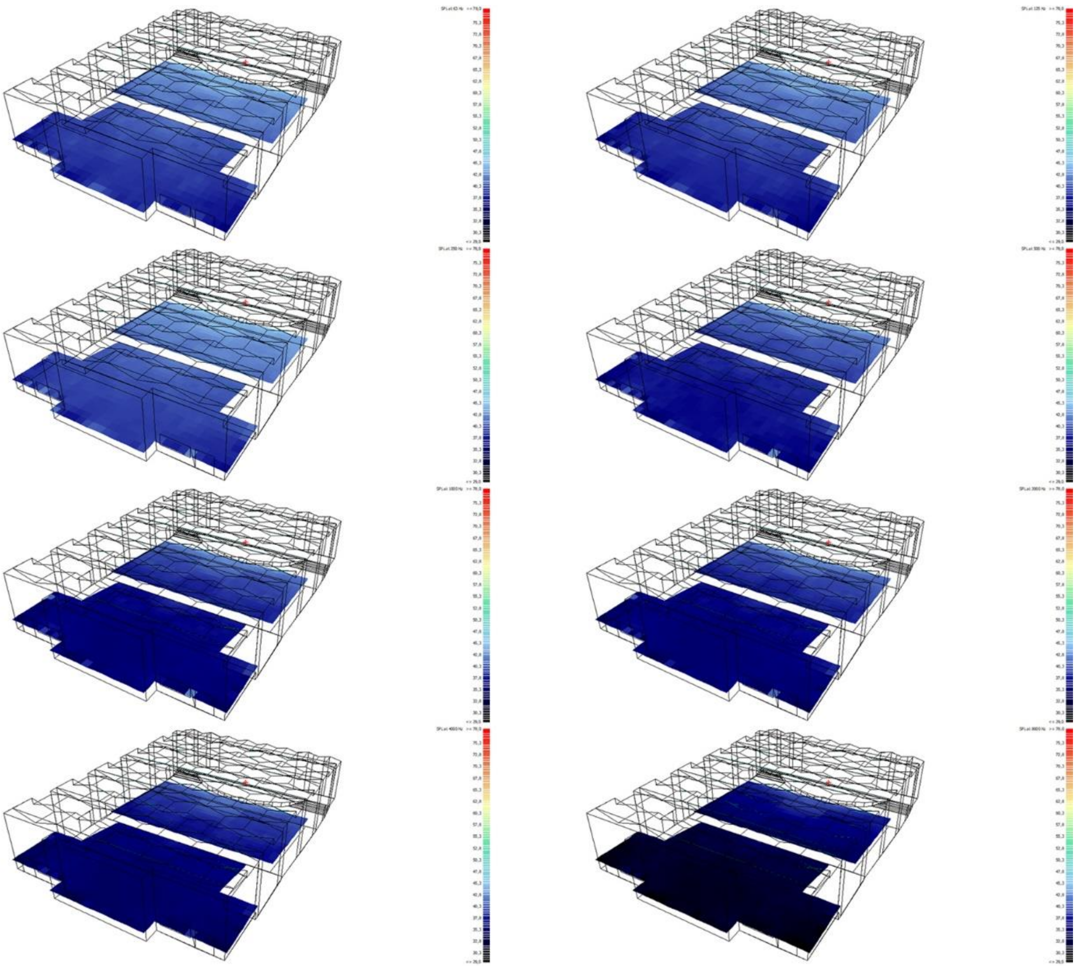


Figure C.22. SPL values in octave bands for Air Force HQ Conference Hall

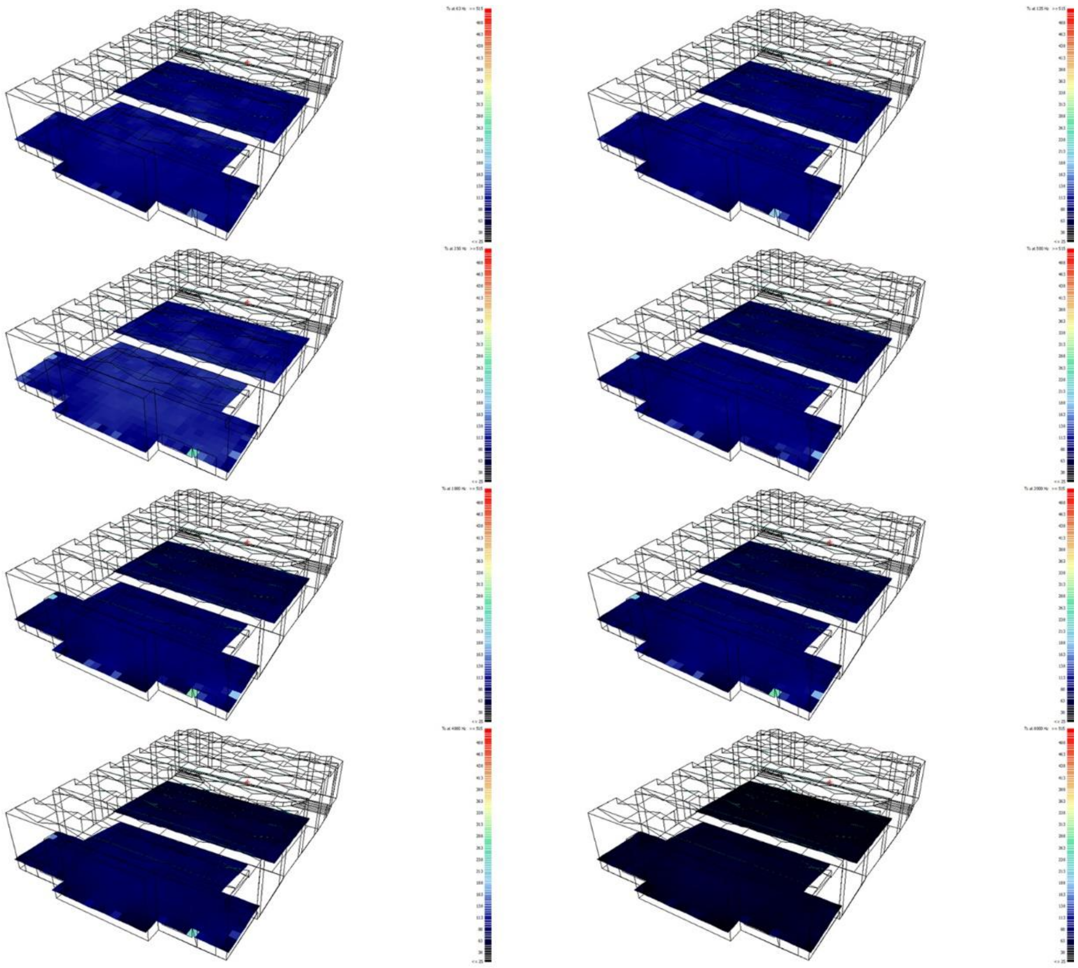


Figure C.23. Ts values in octave bands for Air Force HQ Conference Hall

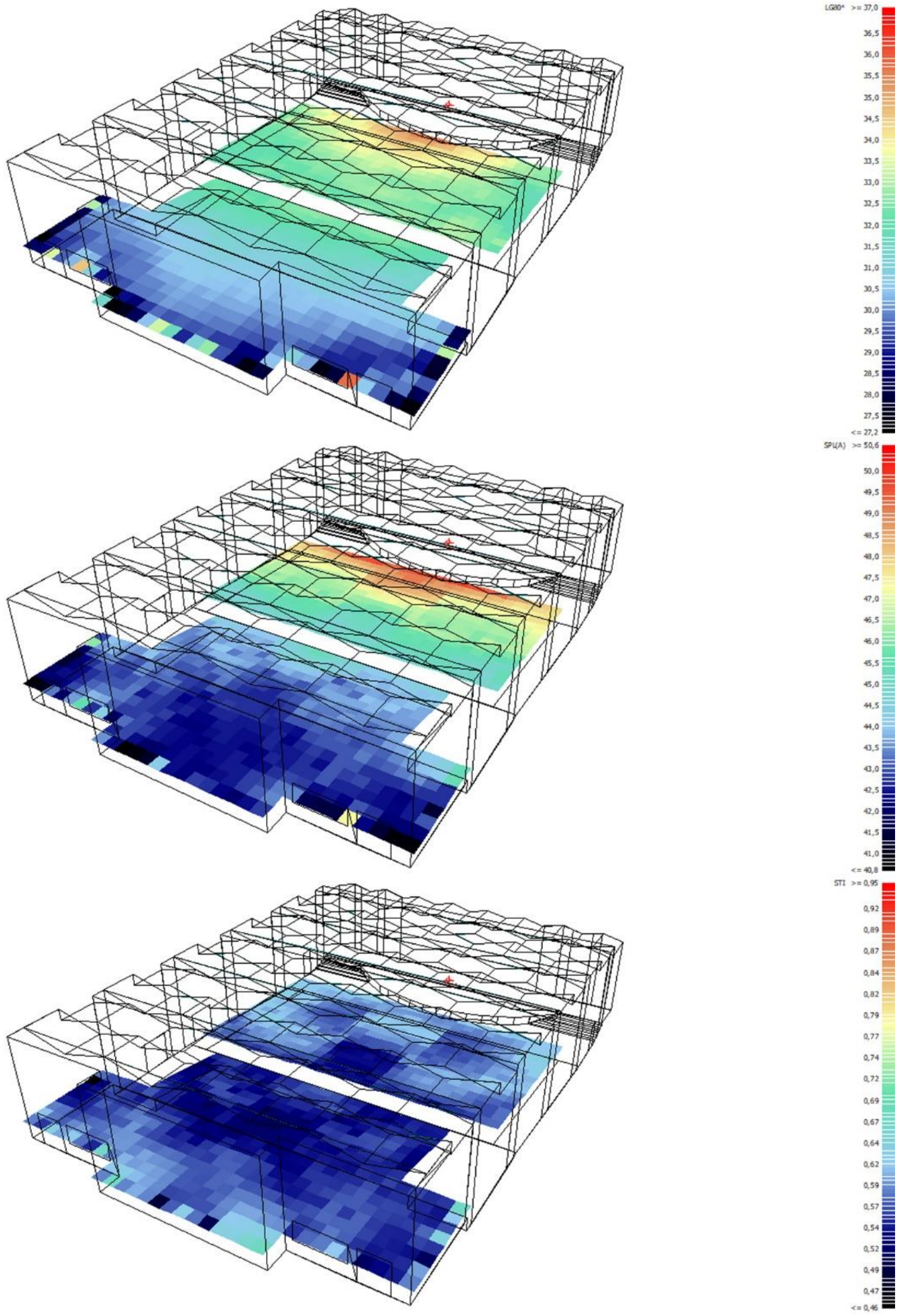


Figure C.24. LG80, SPL(A) AND STI values for Air Force HQ Conference Hall