Technological Educational Institute of Crete
Department of Music Technology and Acoustics

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Measuring acoustic parameters using a Conventional Directional Loudspeaker

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List of Abbreviations

CDLM	Conventional Directional Loudspeaker Method
EDT	Early Decay Time
RT	Reverberation Time
SPL	Sound Power Level
SnR	Signal to Noise Ratio
IAAC	Interaural Cross Correlation
LEF	Lateral Energy Fraction
STI	Speech Transmission Index
MLS	Maximum Length Sequences

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Abstract

For measuring the impulse response and the acoustic parameters of a room, it is common to use an omnidirectional dodecahedron loudspeaker as a sound source. The use of a dodecahedron loudspeaker is the most reliable and common way of conducting acoustic measurements, although there are alternative ways of sound field excitation. The dodecahedron loudspeaker is utilized by many impulse response measurement methods, such as Maximum Length Sequence (MLS), Inverse Repeated Sequence (IRS), Time-stretched Pulses, Sine-sweeps, etc. Unfortunately, the required dodecahedron loudspeaker equipment is costly. This thesis statement titled "Measuring Acoustic Parameters Using a Conventional Directional Loudspeaker" discusses a new method of measuring the acoustic parameters of a room, not by using an omnidirectional loudspeaker as usual, but by using a loudspeaker for domestic use. The aim of this dissertation is to create a new method that will provide accurate results compared to measurements using a dodecahedron loudspeaker, but with minimal cost. During this thesis statement, impulse response measurements were taken by applying the method to spaces of different size and different source-speaker locations. Meanwhile, measurements were taken using a dodecahedron loudspeaker. The acoustic parameters that resulted from the experimental data were extracted and compared. From the results that emerged, conclusions are drawn on the effectiveness of the method, and future work is discussed.

Περίληψη

Προκειμένου να μετρηθεί η κρουστική απόκριση και οι ακουστικές παράμετροι ενός δωματίου, είναι συνηθισμένο να χρησιμοποιείται ένα παντοκατευθυντικό δωδεκαεδρικό ηχείο ως πηγή ήχου. Η χρήση του δωδεκάεδρου ηχείου είναι ο πιο αξιόπιστος και κοινός τρόπος διέγερσης του ακουστικού πεδίου, αν και υπάρχουν και άλλοι εναλλακτικοί τρόποι. Το δωδεκάεδρο ηχείο χρησιμοποιείται σε πολλές μεθόδους εύρεσης της κρουστικής απόκρισης, όπως τα Maximum Length Sequence (MLS), Inverse Repeated Sequence (IRS), Time-stretched Pulses, Sine-sweeps κλπ. Δυστυχώς, το κόστος ενός δωδεκάεδρου ηχείου είναι αρκετά μεγάλο. Η πτυχιακή αυτή με τίτλο "Μέτρηση ακουστικών παραμέτρων με χρήση συμβατικού κατευθυντικού ηχείου" παρουσιάζει μια νέα μέθοδο μέτρησης των ακουστικών παραμέτρων ενός δωματίου, όχι με τη χρήση ενός παντοκατευθυντικού ηχείου όπως συνήθως, αλλά με τη χρήση ηχείου για οικιακή χρήση. Σκοπός της παρούσας πτυχιακής είναι να προτείνει μια καινούργια μέθοδο που θα παρέχει αξιοπρεπή και ακριβή αποτελέσματα σε σύγκριση με τις μετρήσεις χρησιμοποιώντας ένα δωδεκάεδρο ηχείο, αλλά το κόστος εφαρμογής θα είναι ελάχιστο λόγω του ότι θα χρησιμοποιείται ένα κοινό συμβατικό ηχείο. Κατά τη διάρκεια αυτής της πτυχιακής, οι μετρήσεις κρουστικής απόκρισης θα ληφθούν εφαρμόζοντας τη μέθοδο σε χώρους διαφορετικού μεγέθους και σε διαφορετικές θέσεις ηχείων-πηγών. Εν τω μεταξύ, οι ίδιες μετρήσεις θα ληφθούν χρησιμοποιώντας και ένα δωδεκάεδρο ηχείο. Στη συνέχεια θα εξαχθούν και θα συγκριθούν οι ακουστικές παράμετροι που θα προκύψουν από τα πειραματικά δεδομένα. Από τα αποτελέσματα που θα προκύψουν, θα εξαχθούν συμπεράσματα σχετικά με την αποτελεσματικότητα της μεθόδου, θα ληφθούν υπόψη οι βελτιώσεις της μεθόδου και θα συζητηθούν πιθανές μελλοντικές εξελίξεις.

Chapter 1

Introduction

Throughout the 21^{st} century, the field of acoustics has played a major role in how people consider the aspect of sound. With the growth of population and constructions, more and more attention is given to the science of acoustics and how it affects everyday life. Although, what seems to be a great problem, is the tremendous amount of cost needed to conduct an acoustic research which will help resolve the problems of a noisy environment. The general idea behind this thesis statement is to ensure that alternative methods of conducting acoustic researches do exist, and that such researches can be conducted with the least possible amount of cost. Through this thesis statement, we might be able to achieve a new way of measuring acoustical parameters of a room without the need of expensive equipment, but of course, with the same accuracy that a very expensive equipment can provide. Acoustics researches must continue to employ, because providing a room with good acoustics contributes to a good quality of life, can be a contributing factor to teaching and learning when exists in school or university classrooms, can help monitor the noise pollution caused by public transport or noisy halls and many more.

1.1 Background

Acoustical Impulse Response Measurements

According to the BS EN ISO 3382-1-2009 an impulse response is the *temporal evolution of the sound pressure observed at a point in a room, as a result of the emission of a Dirac*

impulse at another point in the room.

Impulse response measurements are probably one of the best tools in the hands of an acoustic engineer. Measuring the impulse response of a room can help one determine all those acoustic parameters which, with the necessary corrections, can highlight the acoustic status of a room. Most of the acoustic parameters such as reverberation time and energy decay of a room, can be defined by the impulse response method with the use of a microphone and a source, both of which combine an omnidirectional property.

1.2 Overview of the thesis

Scope

The scope of this thesis statement is to develop a new way of measuring the reverberation time of a room using an alternative source of sound. The basic idea is to use the dodecahedron loudspeaker as a guide, and by putting a loudspeaker for domestic use in its twelve (12) angles and emitting sounds, such as the MLS and the Sweep Sine method of impulse response measurement, achieve sufficient results which will lead us to the conclusion that an acoustic engineer can measure acoustic parameters such us the reverberation time without the use of a dodecahedron loudspeaker but by combining and adding twelve (12) different impulse responses from a loudspeaker for domestic use.

Through this work, a lot of emphasis has been given to the accuracy of the measurements, always bearing in mind that lowering the financial cost of a standard way of measuring impulse responses, and therefore acoustic parameters, must not come into conflict with the accuracy and the correct results of the measurements.

Structural overview of the thesis

This thesis statement is structured as follows.

Chapter 2 describes all those theoretical acoustic fundamentals such us the aspect of sound, the impulse response methods of measurement in its general, the reverberation time and the acoustic parameters of a room in its entirety.

Chapter 3 describes the method that the BS EN ISO 3382-1-2009 declares and all that vital information needed for the understanding of the thesis statement.

Chapter 4 describes the results of measuring an impulse response using a loudspeaker for conventional use, the analysis of those results, and a comparison with measurements that follow the standard procedure as stated in the BS EN ISO 3382-1-2009.

Chapter 5 is the conclusion of this thesis statement, in which, the sustainability of this method and future developments are stated.

Chapter 2

Acoustic Fundamentals

2.1 Introduction

In the chapter that follows, the acoustic fundamentals of architectural acoustics are stated. Those acoustic fundamentals are the Subjective and Objective criteria of acoustics, the Reverberation time, the Early Decay Time, the Clarity, the Definition, the Background noise, the Surface sound pressure level, the Sound power level and the aspect of sound in general.

2.2 Subjective Criteria of Acoustics

There are several criteria which separate an audibly “good” from and audibly “poor” room. The subjective criteria are the one which are inseparably connected with the human hearing and how each person understands the aspect of sound. One of the most important criterion is the Pitch, which is the subjective response of the ear to the frequencies. Another important criterion, which is directly related to the type of the sound source is the Timbre, which is the subjective characteristic of the sound that makes it possible to separate two tones of the same intensity and fundamental frequency but with different waveforms. Audibility is another important criterion and it is defined as the total response of the ear to the sound. There are quite a few units of measurements for those criteria such us the Phon, which measures the level of audibility, the Sone which measures the subjective audibility and the PndB which measures the level of noisiness (Δημήτριος Σκαρλάτος, *Εφαρμοσμένη Ακουστική*, Εκδόσεις GOTSIS, Τρίτη Έκδοση, ISBN 960-87810-1-3).

2.3 Objective Criteria of Acoustics

The Objective Criteria of Acoustics are those which, throughout calculations, provide us with the information we need about the acoustic quality of a room. One of the most important criterion is with no doubt, the Reverberation Time. Furthermore, other important criteria are the Early Decay Time, the Clarity of a room, and the Definition of a room. The above criteria will be further analyzed throughout the thesis statement, both as concepts and as mathematical models (Δημήτριος Σκαρλάτος, *Εφαρμοσμένη Ακουστική*, Εκδόσεις GOTSIS, Τρίτη Έκδοση, ISBN 960-87810-1-3).

2.4 Reverberation Time

Reverberation time (T_{60}) is defined as the time needed for the noise level (L_p) to diminish to a level of 60 decibels below its original, after the sound source has stopped emitting. Reverberation time plays a vital role in room acoustics because it is inseparably connected with the acoustic quality of a room. The basic theory of reverberation time leads to the classic method of measuring it. A source is emitting successively in all frequency bands and the reverberation time is calculated via the use of a measuring software. At the same time, the reduction of the sound level is being recorded depending on time, and the time interval for the reduction of the sound level in a degree of 60 dB is calculated.

The approximate calculation of the reverberation time, in rooms with low absorption, has been given by Sabine in the late 1890s. He established a relationship between the T_{60} of a room, its volume, and its total absorption (in Sabins). This is given by the equation,

$$T_{60} = \frac{0.161V}{A_s} \qquad 2.1$$

where T_{60} is the reverberation time, V is the volume of the room in m^3 and A_s is the total absorption of the room in Sabins.

As far as big rooms concern, one of the most detailed studies in the field of acoustics was developed by Norris – Eyring. According to them a very accurate way of approaching the reverberation time of a big room is given by the equation:

$$T_{60} = \frac{0.161V}{A_N} \quad 2.2$$

Where T_{60} is the reverberation time, V is the volume of the room in m^3 and A_N is the total absorption of the room given by the equation

$$A_N = s\ln(1 - \bar{a})^{-1} \quad 2.3$$

Rooms with big values of reverberation time have to deal with great problems in speech transmission because of the masking of the syllables, and rooms with low values of reverberation time have to deal with great problems in rendering melodic sounds (Δημήτριος Σκαρλάτος, *Εφαρμοσμένη Ακουστική*, Εκδόσεις GOTSIS, Τρίτη Έκδοση, ISBN 960-87810-1-3).

As one can easily realize, measuring the reverberation time of a room is a very critical point in an acoustic research. Achieving a relatively correct percentage of reverberation time in a room is a very decisive step to help culminate its acoustics and highlight the unique characteristics of its audibility.

2.5 Early Decay Time

Another important parameter of the acoustics of a room is the Early Decay Time or EDT in brief. Early Decay Time is about the first reflections and how they affect the overall acoustics of a room. It is defined as six times the period required for the sound to diminish to a level of 10 dB after the sound source has stopped emitting. While the EDT is a lot like the RT60, it is easily understandable that they differ in a lot of matters. It is important that the EDT is taken under consideration when conducting acoustic researches in a room, because it has been confirmed that most of the listeners, characterizes the acoustic of a room based on the levels of the first reflections rather than the overall response of the room in its entirety. A simple equation which gives the connection between the EDT and the RT60 of a room is described below

$$0{,}8 \times \mathrm{RT}_{60} \leq \mathrm{EDT} \leq \mathrm{RT}_{60} \qquad 2.4$$

2.6 Clarity

Clarity is a lot like Definition. Clarity is defined as the proportion of a point of the acoustic energy during the first 80 ms in terms of the total energy of the delayed reflections. Clarity is widely calculated when someone must deal with concert halls because the 80 ms are long enough for the mixing of sounds rather than the 50 ms of the Definition measurement. Clarity is given by the equation:

$$\mathrm{C}_{80} = \frac{\int_0^{80\mathrm{ms}} \{\mathrm{g(t)}^2\}\mathrm{dt}}{\int_{80\ \mathrm{ms}}^{\infty} \{\mathrm{g(t)}^2\}\mathrm{dt}} \qquad 2.5$$

where g(t) is the impulse response of a room.

2.7 Definition

Definition expresses the percentage (%) of the energy reaching on point of the room from the early reflections. It is defined as the ratio, at some point of the acoustic energy during the first 50 ms, in terms of the total energy. A good amount of this percentage can provide a better quality of speech and this is the reason why Definition is extremely important when someone must deal with classrooms or meeting rooms. The equation for calculating the Definition is given below

$$D_{50} = \frac{\int_0^{50ms} P^2(t)dt}{\int_0^{\infty} P^2(t)dt} \times 100\% \qquad 2.6$$

where P(t) is the instantaneous sound pressure in Pa.

2.8 Background Noise

Background noise is defined as any sound other than the sound being monitored. Examples of background noises are environmental noises such as traffic noises from cars, mechanical noises from air conditioning (HVAC noise) and noise from coupled spaces. The prevention and reduction of background noise is essential in the field of active noise control and room acoustics in general. Having a big amount of background noise can affect the overall results of an acoustic measurement.

2.9 Surface Sound Pressure Level

Surface Sound Pressure Level or SPL in brief, is the energy-average of the time-averaged sound pressure levels at all the microphone positions, or traverses, on the measurement surface, with the background noise corrections, $K1$, applied at each microphone position or traverse (BS EN ISO 6926:2014, 2014). The Surface Sound Pressure Level is expressed in decibels and is symbolized as L_p.

2.10 Sound Power Level

Sound Power Level is defined as ten times the logarithm to the base 10 of the ratio of the sound power of a source, P, to a reference value, P_0, expressed in decibels (BS EN ISO 6926:2014, 2014). The mathematical approach is stated below

$$L_W = 10\log\frac{P}{P_0} \tag{2.7}$$

where the reference value, P_0, is 1 Pw.

2.11 Sound Strength

It is known that, in an interior space, the sound is enhanced by the reflections that derive from the surrounding walls. This enhancement depends on the geometry of each room as well as the absorption coefficient of the different surfaces. For the quantification of this enhancement, the factor of sound strength is used. The sound strength occurs if we subtract the level that corresponds to the directly transmitted sound energy from the total measured level of the room. Mathematically the sound strength is defined as

$$G = 10\log \frac{\int_0^{80ms}\{g(t)^2\}dt}{\int_0^{\infty}\{g_A(t)^2\}dt} \qquad 2.8$$

Where g(t) is the impulse response of the measured space

g_A(t) is the impulse response of the sound source measured in an anechoic chamber

It is also proven that the Strength factor can also be calculated with the equation

$$G = 10\log \frac{T_{60}}{V} + 45\ dB \qquad 2.9$$

2.12 Signal to noise ratio

As signal to noise ratio (SNR), we determine the ratio of the desired sound to ambient noise. The signal-to-noise ratio is usually lower at the back of the room or near a noise source (air conditioning unit). Seep,

$$SNR = 10\log\frac{p_{sig}^2}{p_{noise}^2} = 10\log\frac{\frac{p_{sig}^2}{p_{ref}^2}}{\frac{p_{noise}^2}{p_{ref}^2}} = 10\log\frac{p_{sig}^2}{p_{ref}^2} - 10\log\frac{p_{noise}^2}{p_{ref}^2} = L_{sig} - L_{noise} \qquad 2.10$$

Glosemeyer, Hulce, Linn, & Aytar, 2000) The signal to noise ratio is describes by the equation

Where p_{sig} , p_{noise} are the sound pressures of the signal and the noise respectively

The signal to noise ratio equals the difference between the level of the signal subtracting the level of the background noise. Signal to noise ratio plays a vital role in speech intelligibility as stated by the (ISO 9921-1) in the table that follows

Signal to noise ratio (dB)	**Speech Intelligibility**
< -6	Insufficient
-6 to 3	Unsatisfactory
-3 to 0	Sufficient
0 to 6	Satisfactory
6 to 12	Good
12 to 18	Very Good
> 18	Excellent

Table 2.1: Speech intelligibility for different Signal to noise ratios according to ISO 9921-1.

2.13 Recommended indicator values

The following table presents the recommended acoustic indicator values measured in two different empty spaces as a guidance to which value every acoustic parameter should have in different interior spaces

Indicator	**Music**	**Symphonic Orchestra**
Size/Numbers of seats	2500 m^3/ 300	25000 m^3/ 2000
Reverberation time (T_{60})	1.5 s	2 to 2.4 s
Early Decay Time (EDT)	1.4 s	2.2 s
Sound strength	10 dB	3 dB
Clarity (C_{80})	3 dB	-1 dB
Lateral Energy Fraction (LEF)	0.15 to 0.20	0.20 to 0.25
Interaural Cross Correlation (IACC)	0.6	0.7

Table 2.2: Recommended acoustic indicator values.

The following table presents the recommended Reverberation time for constants A and B in different interior rooms depending on their use

Type of room	**A**	**B**
Cathedrals – Concert Halls	0.4	0.22
Churches – Opera Houses	0.3	0.16
Cinemas – Music Halls	0.22	0.11
Lecture Spaces - Studios	0.2	0.11

Table 2.3: Recommended reverberation time for constants A and B.

On the above spaces of table 2, the volume of the room is in m^3 and corresponds to a frequency of 500 Hz. To measure mathematically the generally accepted Reverberation times one can use the equation

$$T_{60} = A\log V + B \qquad 2.11$$

2.14 Interaural Cross Correlation (IACC)

The Interaural Cross Correlation (IAAC) is defined as the difference of the two sounds that reach the ears of the listeners and is used in architectural acoustics to determine quantitatively the perception of the spatial distribution and the quality of the sound in a room. Considering that p_R(t) and p_L(t) are the sound signals that reach the right and left ear of a person, then the IACC is defined by the equation

$$IACC(\tau) = \frac{\int_{t_1}^{t_2} p_L(t)p_R(t+\tau)dt}{(\int_{t_1}^{t_2} p_L^2(t)p_R^2(t+\tau)dt)^{\frac{1}{2}}} \qquad 2.12$$

When the two sounds are the same, the IACC has a maximum value of 1. When the two sounds are completely different from each other, the IACC has a value of 0. A good value for IACC in a room with good acoustics, the value smaller than 0.4 is considered to be sufficient. Moreover, it is important to take into consideration the fact that when the limits of integration are 5 ms and 80 ms the IACC is symbolized as $IACC_E$

and indicates the spaciousness of a room. However, when the limits of integration are 80 ms and 3 ms the IACC is symbolized as $IACC_L$ and indicates the diffuseness of the reverberating field.

2.15 Lateral Energy Fraction (LEF)

The Lateral Energy Fraction or LEF in brief, indicates the percentage of the energy from lateral reflections that reach the listener at the first 80 ms, compared with the total amount of energy that the source emits. To measure this indicator, the use of two microphones is essential, of which the one is isotropic and the other has a polar diagram of a figure of 8 (Σκαρλάτος).

2.16 Center Time (T_S)

The center time (T_S) indicator, shows us the objective determination of the perceptuality of the speech. When T_S has a low value, the sound is more clear and understandable as opposed to when it has a big value. Centre time is very important when dealing with a room that is directly connected to speech because, unlike the D_{50} or the C_{50} indicators, it does not focus on the short 50 ms period so it gives us a more overall perception of speech intelligibility (Δημήτριος Σκαρλάτος, *Εφαρμοσμένη Ακουστική*, Εκδόσεις GOTSIS, Τρίτη Έκδοση, ISBN 960-87810-1-3). The center time can be calculated with the use of the below mathematical equation

$$T_S = \frac{\int_0^{\infty} P(t)dt}{\int_0^{\infty} P(t)dt} \qquad 2.13$$

2.17 Speech Transmission Index (STI)

The speech transmission index indicates the percentage of the correct syllables that the average listener understands, bearing in mind the background noise and the reverberation time of the room measured (Δημήτριος Σκαρλάτος, *Εφαρμοσμένη Ακουστική*, Εκδόσεις GOTSIS, Τρίτη Έκδοση, ISBN 960-87810-1-3). The values that the STI indicator can receive are between 0 and 1, with 1 considered to be excellent. The table below presents the speech intelligibility for different STI values

Speech Transmission Index (STI)	Speech intelligibility
1 > STI > 0.75	Excellent
0.75 ≥ STI > 0.60	Very good
0.60 ≥ STI > 0.45	Mediocre
0.45 ≥ STI > 0.32	Poor
0.32 ≥ STI > 0	Bad

Table 2.4: Speech intelligibility for various Speech Transmission Indexes.

2.18 T10, T20 and T30 indicators

The T_{30} indicator is defined as twice the time needed for the sound to diminish from -5 to -35 dB after the sound source has stopped emitting. The T_{20} indicator is defined as twice the time needed for the sound to diminish from -5 to -25 after the sound source has stopped emitting. The T_{10} indicator is defined as twice the time needed for the sound to diminish from -5 to -15 after the sound source has stopped emitting.

Chapter 3

Specific Information Concerning the new Method

3.1 Introduction

In the chapter that follows, specific information about the conventional directional loudspeaker measurement method and the understanding of this thesis statement is given. That information includes the BS EN ISO 3382-1:2009, the dodecahedron loudspeaker as a sound source, the impulse response as a measurement method, other impulse response measurement techniques and a presentation of the new conventional directional loudspeaker measurement method.

3.2 BS EN ISO 3382-1:2009

As the (BS EN ISO 3382-1:2009, 2009) clearly states, to measure the acoustic parameters of a room and specifically the reverberation time, the acoustic engineer needs a sound source which should be as close to omnidirectional as possible (see Table 1). It shall produce a sound pressure level sufficient to provide decay curves with the required minimum dynamic range, without contamination by background noise.

Frequency, hertz	125	250	500	1000	2000	4000
Maximum deviation, decibels	± 1	± 1	± 1	± 3	± 5	± 6

Table 3.1: Maximum deviation of directivity of source in decibels for excitation with octave bands of pink noise and measured in free field.

3.3 The Dodecahedron loudspeaker as a sound source

An omnidirectional sound source is essential in room acoustical measurements (BS EN ISO 3382-1:2009, 2009). The omnidirectional directivity of a sound source is commonly approached by placing 12 loudspeakers in a regular 12-face polyhedron, called a dodecahedron. Figure 1 shows the directivity polar plot of a dodecahedron loudspeaker.

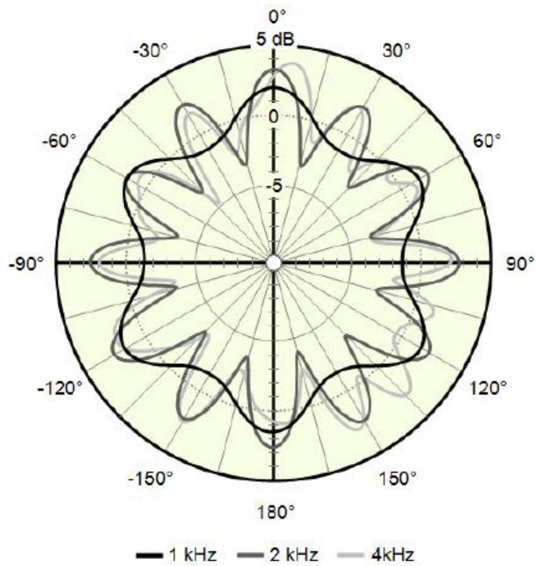

Figure 3.1: Horizontal directivity of a dodecahedron sound source.

3.4 Impulse response as a measuring method

Impulse response is one of the simplest way of measuring the acoustic parameters of a room. According to this method, the room is stimulated with a sound source which suddenly stops. In the past decades, acoustic engineers improvised many ways of measuring the impulse response using either balloons that suddenly popped or acoustic pistols that fired. However, those methods, cannot satisfy a suitable dynamic range for low frequencies. Pulse duration, by definition, is very short and it is very difficult to deliver enough energy to overcome the background noise. Also, as stated above, (see (BS EN ISO 3382-1:2009, 2009), the source must be as close to omnidirectional as possible. Nowadays, and with the growth of computers, the most popular way of measuring the impulse response of a room is by using the MLS or the Sweep Sine method, and with the proper equipment and FFT analysis the results are given to the engineer by a computer. The MLS method, developed by Schroder and Alrutz (H. Alrutz, 1983), comes with the full name of Maximum Length Sequences and describes a measuring method which emits a pseudo-random sequence of numbers.

The period of the MLS sequence is

$$l = 2^n - 1 \tag{3.3}$$

where *n* is every positive integer.

Every sample of the sequence has the value of +1 or -1, which means that it consists of Dirac functions (Σκαρλάτος).

The exponential Sine Sweep, is a method, which gained a lot of popularity in recent years (2000 and later) and its usage became much larger thanks to the effectiveness of modern technology. The exponential Sine Sweep method, employs a loudspeaker playing a continuous sinusoidal sound instead of an impulsive source. The sound is simultaneously played and recorded. Afterwards, the recording is processed, with a mathematical procedure called “deconvolution”, which reconstructs the impulse response from the not-impulsive recorded signal. (Farina, 2000)

3.5 Other Impulse Response Measurement methods

Alternative methods of measuring the impulse response of a room are constantly being used by engineers. Although the disadvantages are noticeable, there is one great advantage in those alternative methods, which is the little amount of finance needed to conduct the measurement. As stated above, the impulse response measurement is the response of the physical system to a Dirac delta function. Nowadays, the MLS and the Sine-sweep methods are the most common in use, but in the past decades other methods where the most widespread. Those methods are the balloon which pops, making a sudden sound that suddenly stops, the acoustic pistol which fires, a firecracker that explodes or a wooden clapper that claps and suddenly stops. The greater disadvantage of those methods is that they cannot produce a very wide decay range especially on the low frequencies and also, they are not sufficient enough to overcome the background noise of the room where the study takes place.

3.6 Presentation of the conventional directional loudspeaker method

This thesis statement analyzes the existence of a specialized impulse response measurement method with the use of a conventional directional loudspeaker, instead of an omnidirectional one. As stated above, the dodecahedron loudspeaker consists of twelve loudspeakers in each of its twelve sides (see figure 3.2). The general idea behind this new method is to place the single directional loudspeaker in each of the twelve sides of the dodecahedron, making it indirectly omnidirectional by adding the twelve different impulse response measurements taken. At first, measurements were taken using the dodecahedron loudspeaker as defined by the (BS EN ISO 3382-1:2009, 2009) and then 12 different measurements, one at each side of the dodecahedron, using the directional loudspeaker. After the measurements were completed, the twelve different measurements were added as one so that they would be able to get compared with the one from the dodecahedron loudspeaker. The processing of the measurements was carried out by the acoustic software “ARTA”, the measurements of the conventional directional loudspeaker method where added with the use of the software “Cubase”.

The results of this comparison will be stated in the chapters that follow.

Chapter 4

Presentation, analysis and comparison of results

4.1 Introduction

In the chapter that follows, there is a presentation of the equipment and the rooms that were used for the measurements of the impulse responses. There is also an analysis of the results obtained from both measurements, those with the dodecahedron and those with the method, and at last a comparison between them.

4.2 Presentation of the equipment

The equipment that was used during this thesis statement is,

- Dodecahedral Loudspeaker type DO12, 01 dB - Stell
- Acoustic Software ARTA
- Fujitsu Lifebook LH532 Laptop
- Loudspeaker type Behringer Truth B2031A Active 2-Way Reference Studio Monitor
- Microphone type 4190, Earthworks

4.3 Presentation of the rooms

The measurement in the small sized room took place in the Acoustic Laboratory of the Technological Educational Institute of Crete, Department of Music Technology and Acoustics, in Rethymnon, Greece. This exact room was chosen because its size and configuration match the majority of rooms throughout the world. The room has a length of 6.26 meters, a width of 4,95 meters and a height of 2.84 meters. The speed of sound inside the room is 343 meters/second. The measurement of the medium sized room took place in a common classroom of the Technological Educational Institute of Crete, Department of Music Technology and Acoustics, in Rethymnon, Greece. This common classroom was chosen because it matches the standards of a conventional medium room and is suitable for demonstrating the results of this new method. The room has a length of 10.7 meters, a width of 6.2 meters and a height of 2.9 meters. The speed of sound inside the room is 343 meters/second.

4.4 General presentation of the measurements

In this section, the measurements of the small and the medium sized room will be presented at a wide frequency range. At first, the measurements conducted in the small sized room of the Institution and afterwards the measurements that took place in the medium sized room of the Institution.

4.4.1 Measurements in the small sized room

Figure 4-1, shows the measurement that was conducted in the small sized room of the Institution. This measurement was taken only with the use of the dodecahedron loudspeaker. The dodecahedron loudspeaker was placed in the center of the room. The distance between the dodecahedron loudspeaker and the ground was 1.10 meters. The microphone was placed in front of the dodecahedron loudspeaker in 1.25 meters. The distance of the microphone from the ground was 1.26 meters. Sine sweep noise was produced from the ARTA software generator and recorded with the use of the microphone and the sound card.

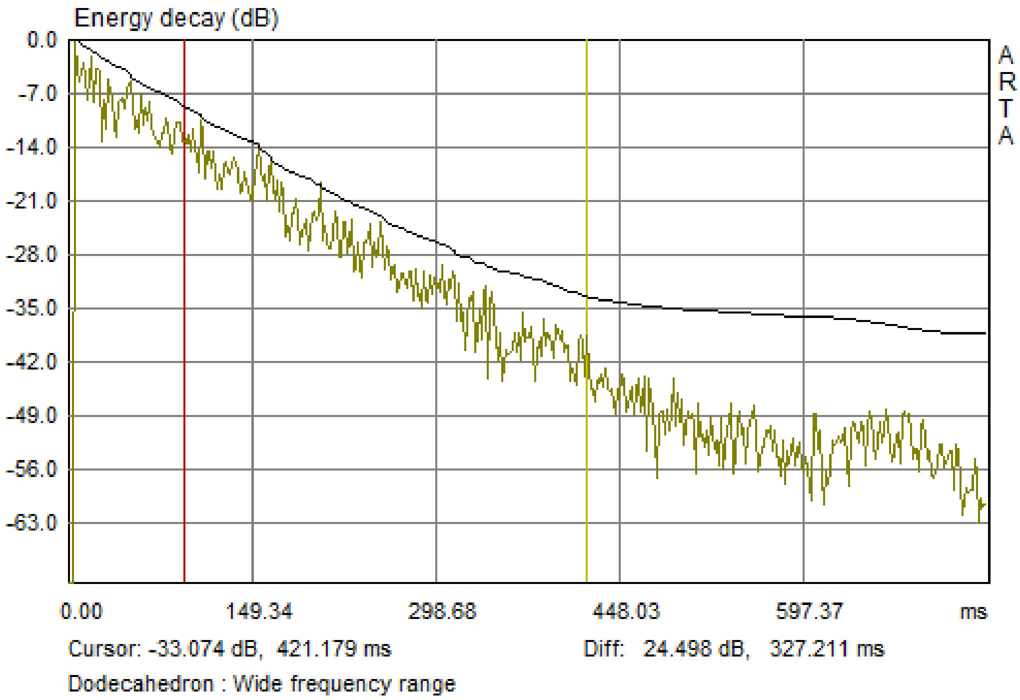

Figure 4-1: Measurement conducted with the dodecahedron loudspeaker presented in wide frequency range

Figure 4-2, shows the measurement that was conducted in the small sized room of the Institution. This measurement was taken with the use of the new conventional directional loudspeaker method. As stated previously, twelve different measurements where added each one taken separately from all the twelve corners of the dodecahedral loudspeaker which was used as a guidance. The distance from the ground as well as from the microphone was the same as the distances from the measurement in figure 3 using the dodecahedron loudspeaker.

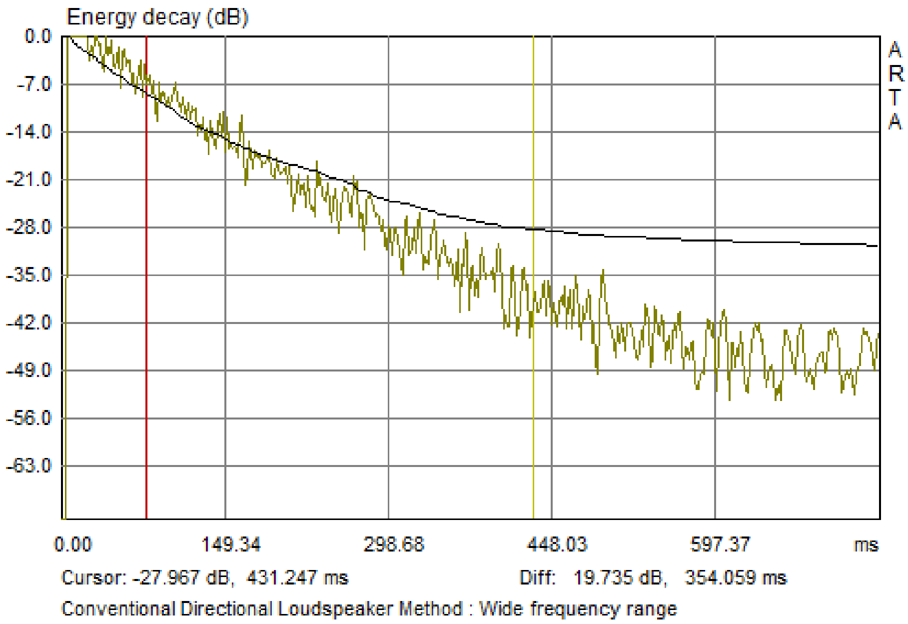

Figure 4-2: Measurement conducted with the use of the CDL method presented in wide frequency range

4.4.2 Measurements in the medium sized room

Figure 4-3, shows the measurement that was conducted in the medium sized room of the Institution. This measurement was taken only with the use of the dodecahedron loudspeaker. The dodecahedron loudspeaker was placed in the center of the room. The distance between the dodecahedron loudspeaker and the ground was 1.10 meters. The microphone was placed in front of the dodecahedron loudspeaker in 1.61 meters. The distance of the microphone from the ground was 1.26 meters. Sine sweep noise was produced from the ARTA software generator and recorded with the use of the microphone and the sound card.

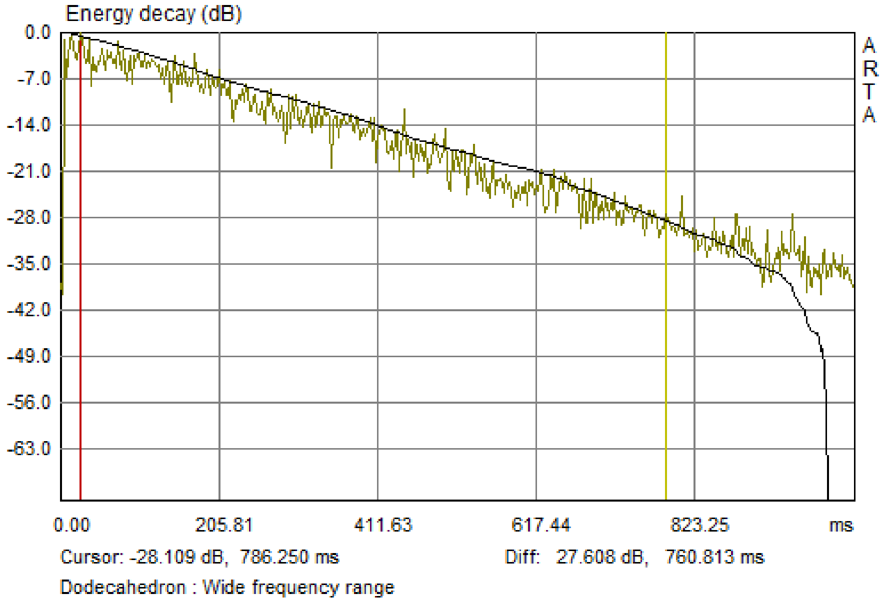

Figure 4-3: Measurement conducted with the dodecahedron loudspeaker presented in wide frequency range

Figure 4-4, shows the measurement that was conducted in the medium sized room of the Institution with the use of the new conventional directional loudspeaker method. The distance from the ground as well as from the microphone was the same as the distances from the measurement in figure 5 using the dodecahedron loudspeaker.

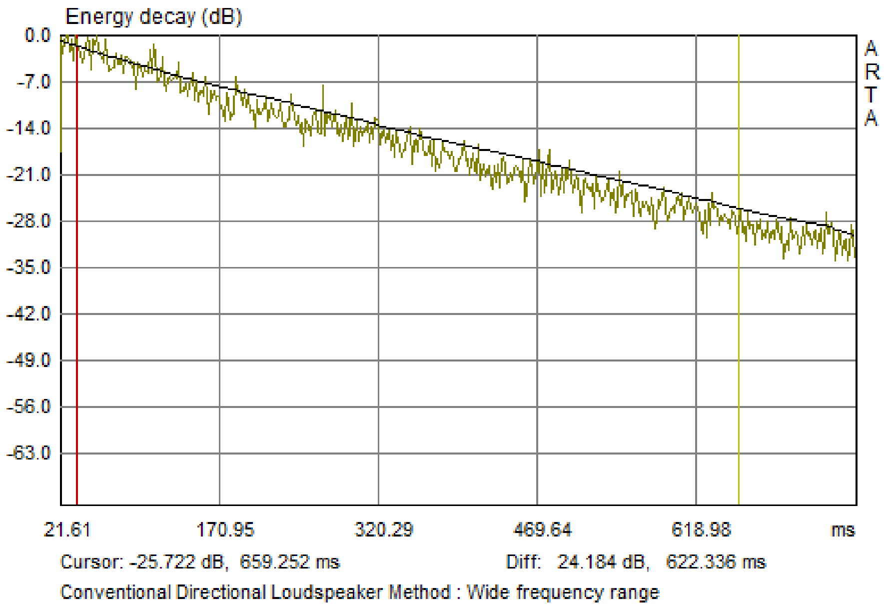

Figure 4-4: Measurement conducted with the use of the CDL method presented in wide frequency range

4.5 Detailed presentation per frequency

In this section, the measurements of the small and the medium sized room will be presented per frequency. At first, the measurements conducted with the dodecahedral loudspeaker will be presented within octave bands and afterwards the measurements that were conducted with the use of the new method.

4.5.1 Small sized room measurement results

Frequency of 62.5 Hz

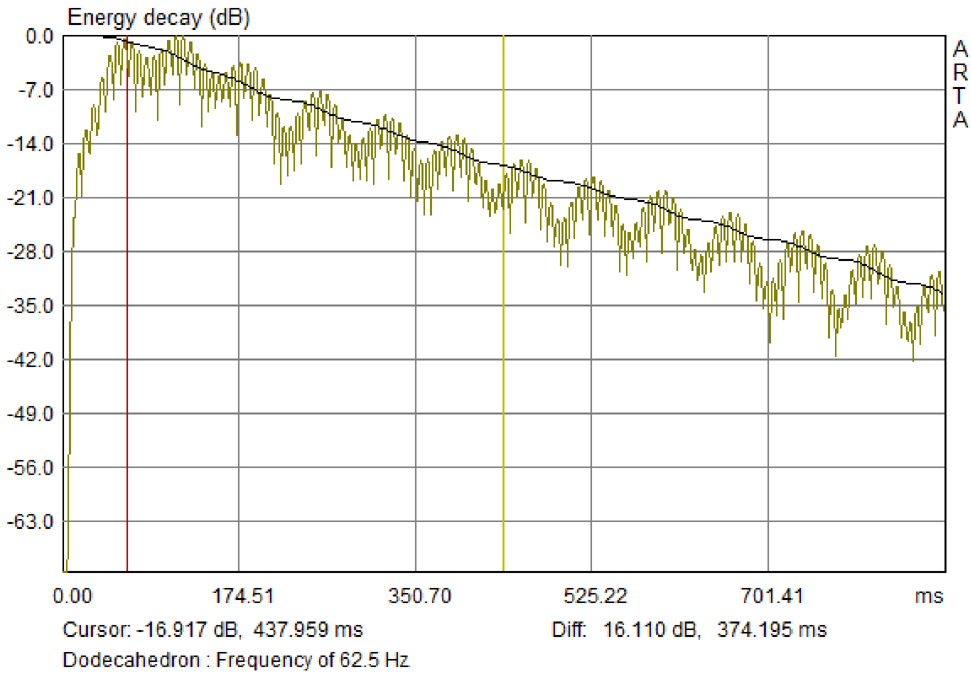

Figure 4-5: *Measurement conducted with the Dodecahedron Loudspeaker for the frequency of 62.5 Hz*

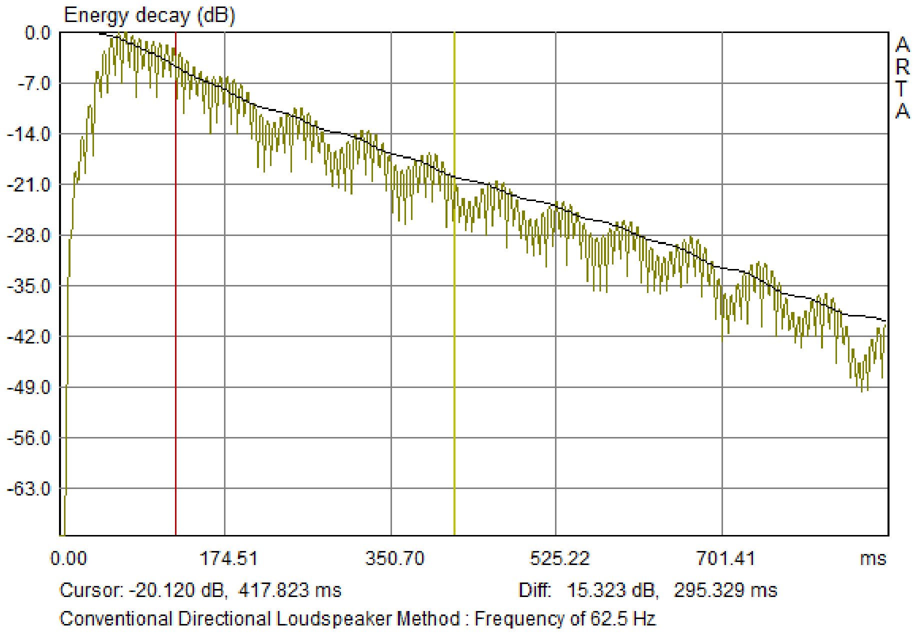

Figure 4-6: Measurement conducted with the CDL method for the frequency of 62.5 Hz

Figure 4-5 and 4-6 present the measurements taken in the small room with the two methods for the frequency of the 62.5 Hz. Figure 4-5 shows a reverberation time of 1.357 sec and figure 4-6 a reverberation time of 1.215 sec.

Frequency of 125 Hz

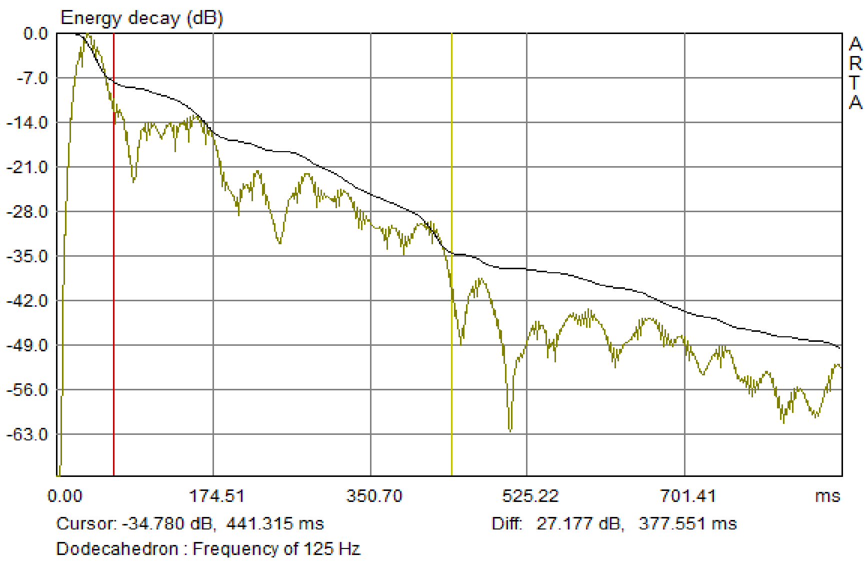

Figure 4-7: Measurement conducted with the Dodecahedron Loudspeaker for the frequency of 125 Hz

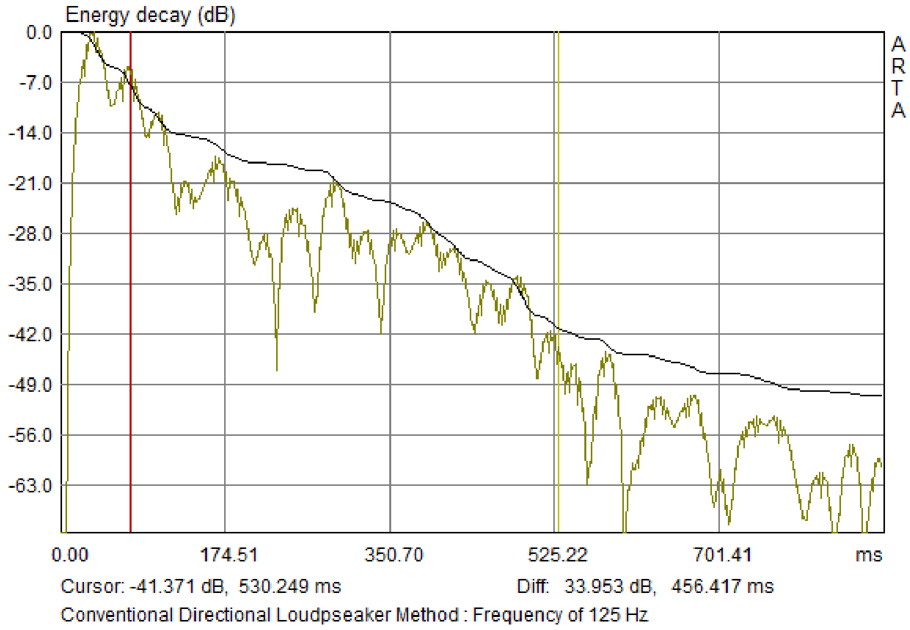

Figure 4-8: Measurement conducted with the CDL method for the frequency of 125 Hz

Figure 4-7 and 4-8 present the measurements taken in the small room with the two methods for the frequency of the 125 Hz. Figure 4-7 shows a reverberation time of 0.911 sec and figure 4-8 a reverberation time of 0.972 sec.

Frequency of 250 Hz

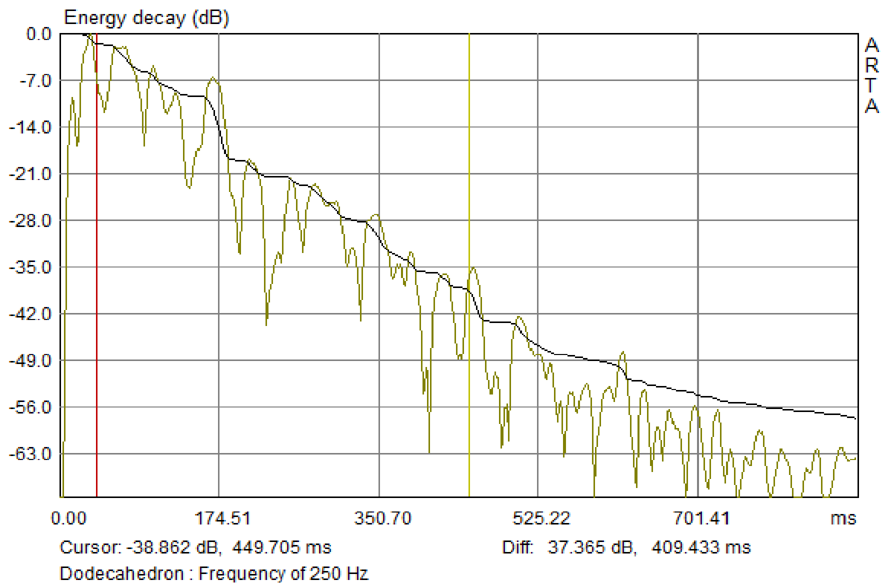

Figure 4-9: Measurement conducted with the Dodecahedron Loudspeaker for the frequency of 250 Hz

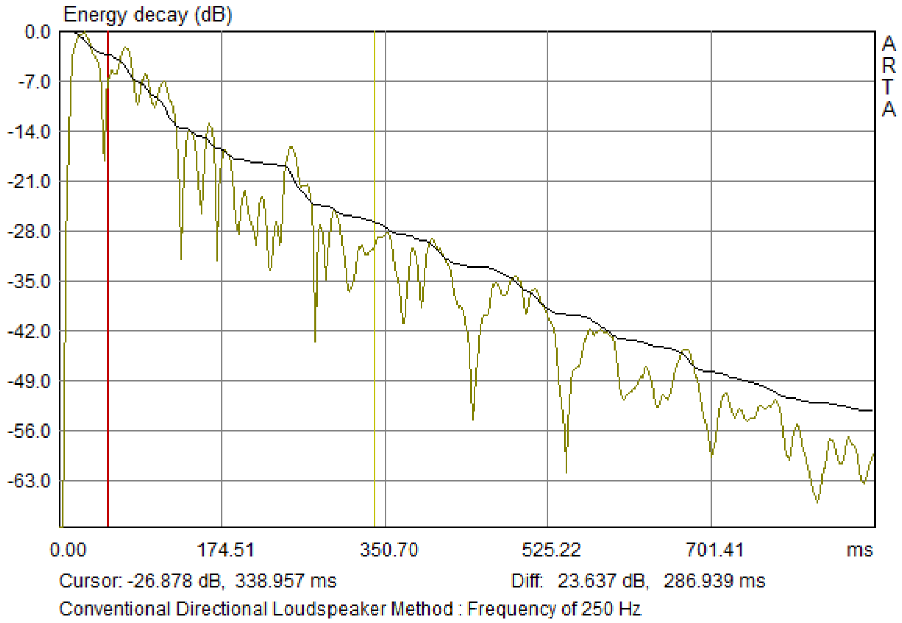

Figure 4-10: Measurement conducted with the CDL method for the frequency of 250 Hz

Figure 4-9 and 4-10 present the measurements taken in the small room with the two methods for the frequency of the 250 Hz. Figure 4-9 shows a reverberation time of 0.633 sec and figure 4-10 a reverberation time of 0.742 sec.

Frequency of 500 Hz

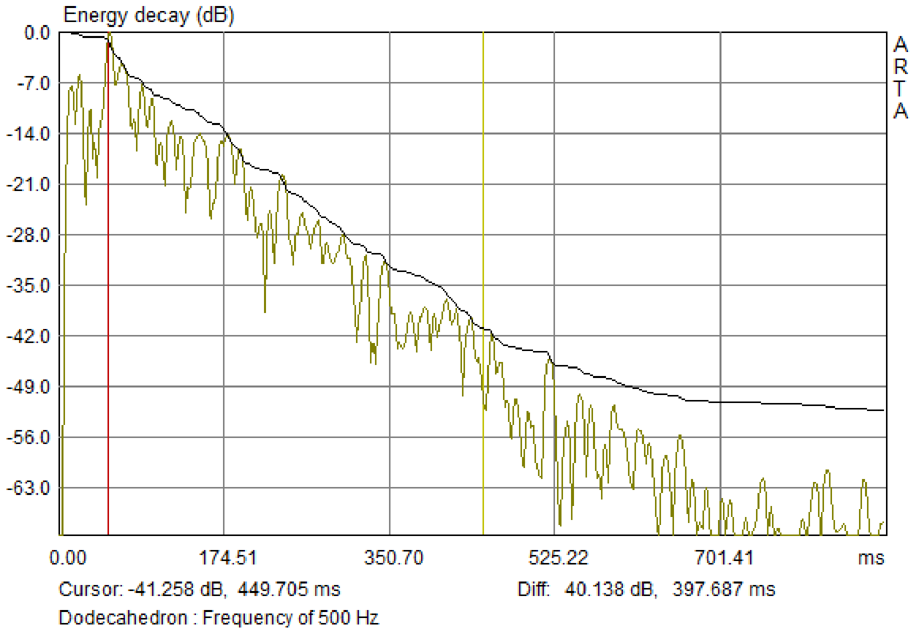

Figure 4-11: Measurement conducted with the Dodecahedron Loudspeaker for the frequency of 500 Hz

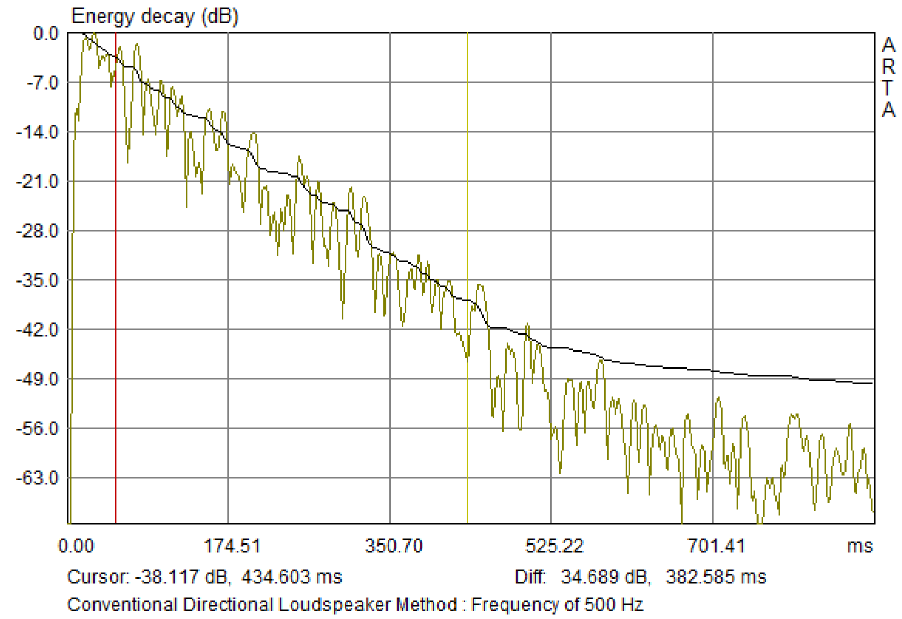

Figure 4-12: Measurement conducted with the CDL method for the frequency of 500 Hz

Figure 4-11 and 4-12 present the measurements taken in the small room with the two methods for the frequency of the 500 Hz. Figure 4-11 shows a reverberation time of 0.628 sec and figure 4-12 a reverberation time of 0.664 sec.

Frequency of 1000 Hz

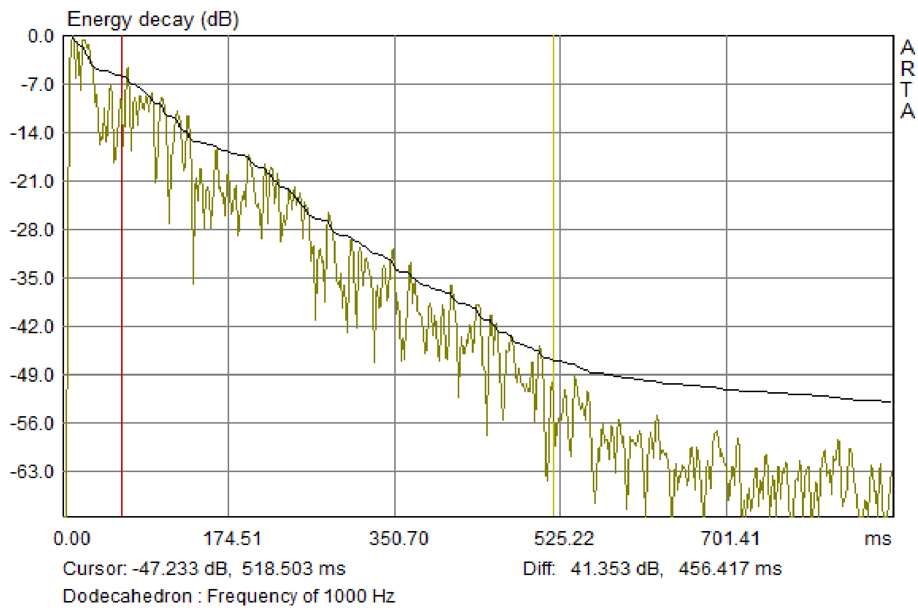

Figure 4-13 Measurement conducted with the Dodecahedron Loudspeaker for the frequency of 1000 Hz

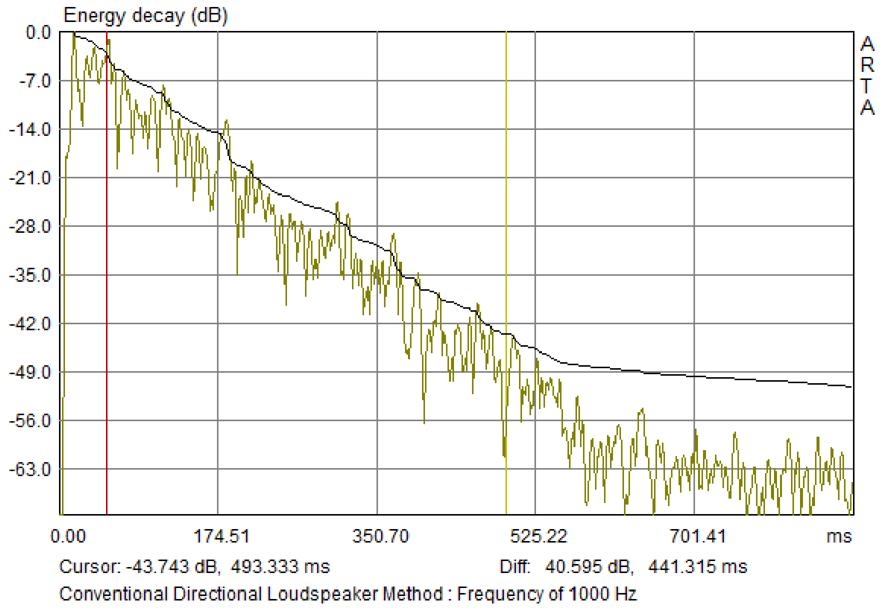

Figure 4-14: Measurement conducted with the CDL method for the frequency of 1000 Hz

Figure 4-13 and 4-14 present the measurements taken in the small room with the two methods for the frequency of the 1000 Hz. Figure 4-13 shows a reverberation time of 0.666 sec and figure 4-14 a reverberation time of 0.660 sec.

Frequency of 2000 Hz

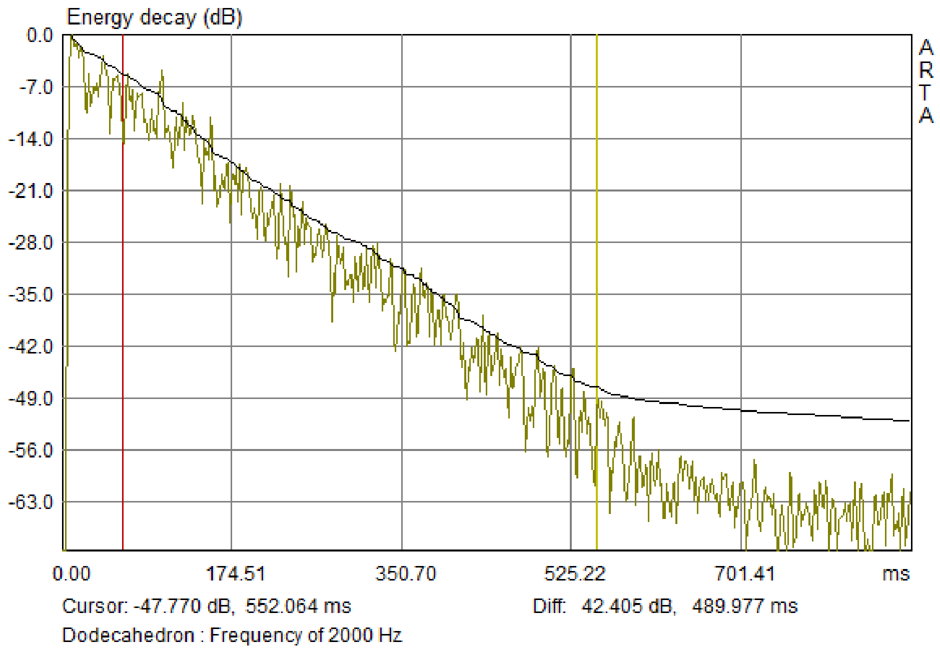

Figure 4-15: Measurement conducted with the Dodecahedron Loudspeaker for the frequency of 2000 Hz

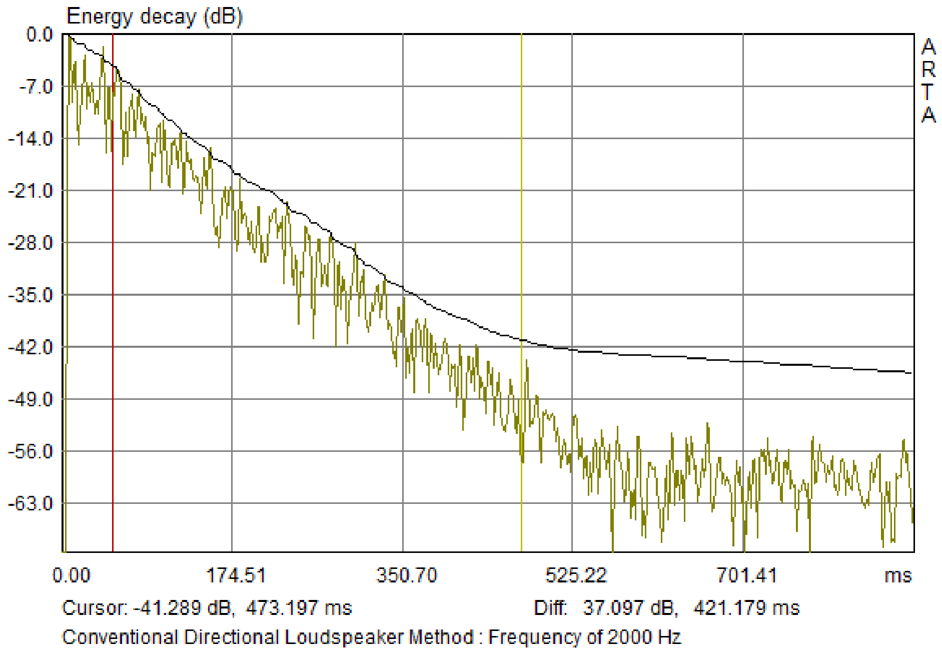

Figure 4-16: Measurement conducted with the CDL method for the frequency of 2000 Hz

Figure 4-15 and 4-16 present the measurements taken in the small room with the two methods for the frequency of the 2000 Hz. Figure 4-15 shows a reverberation time of 0.684 sec and figure 4-16 a reverberation time of 0.674 sec.

Frequency of 4000 Hz

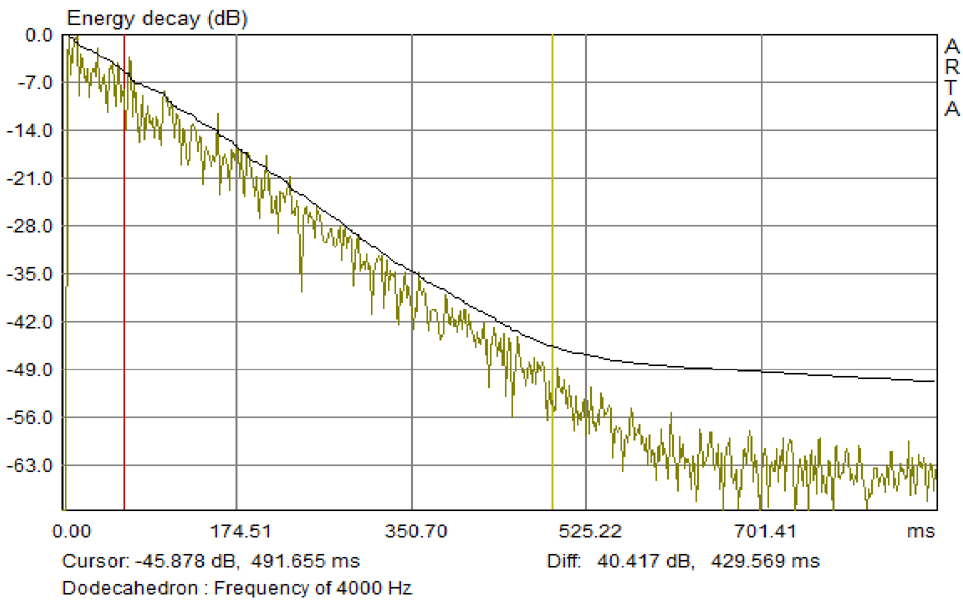

Figure 4-17: Measurement conducted with the Dodecahedral Loudspeaker for the frequency of 4000 Hz

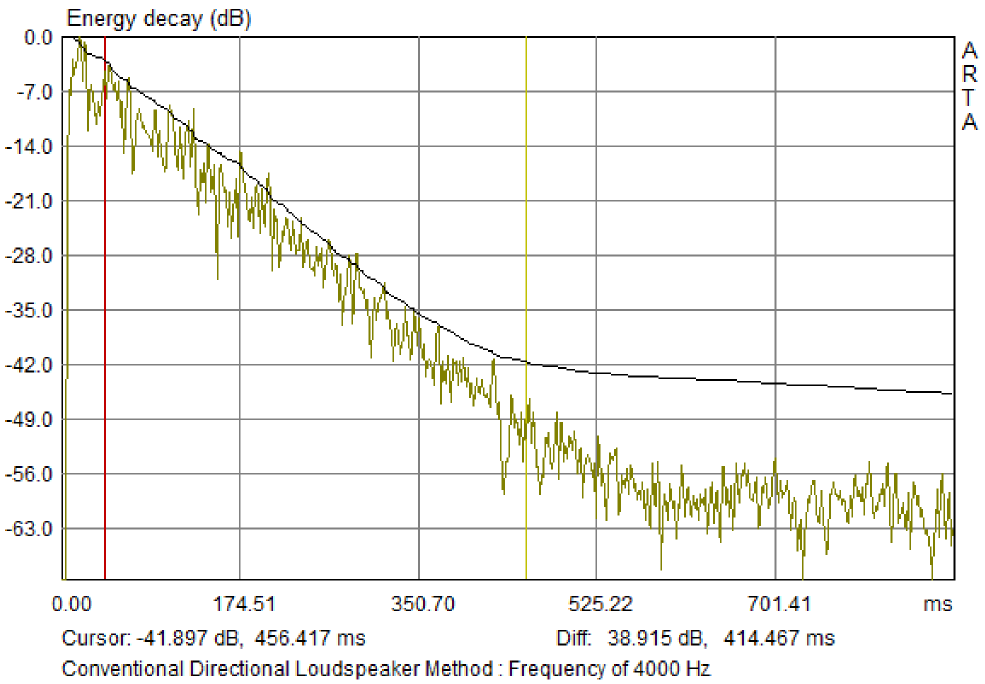

Figure 4-18: Measurement conducted with the CDL method for the frequency of 4000 Hz

Figure 4-17 and 4-18 present the measurements taken in the small room with the two methods for the frequency of the 4000 Hz. Figure 4-17 shows a reverberation time of 0.611 sec and figure 4-18 a reverberation time of 0.605 sec.

Frequency of 8000 Hz

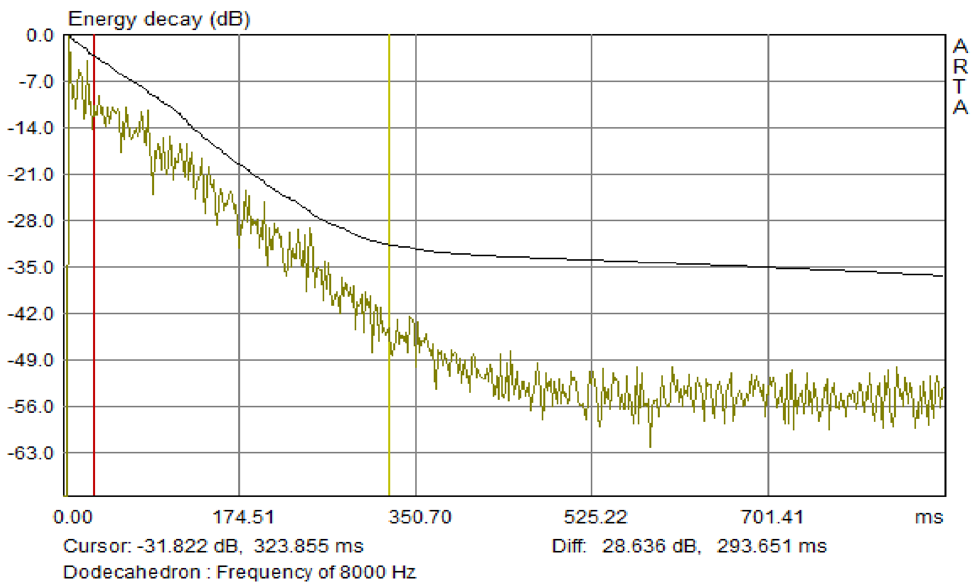

Figure 4-19: Measurement conducted with the Dodecahedron Loudspeaker for the frequency of 8000 Hz

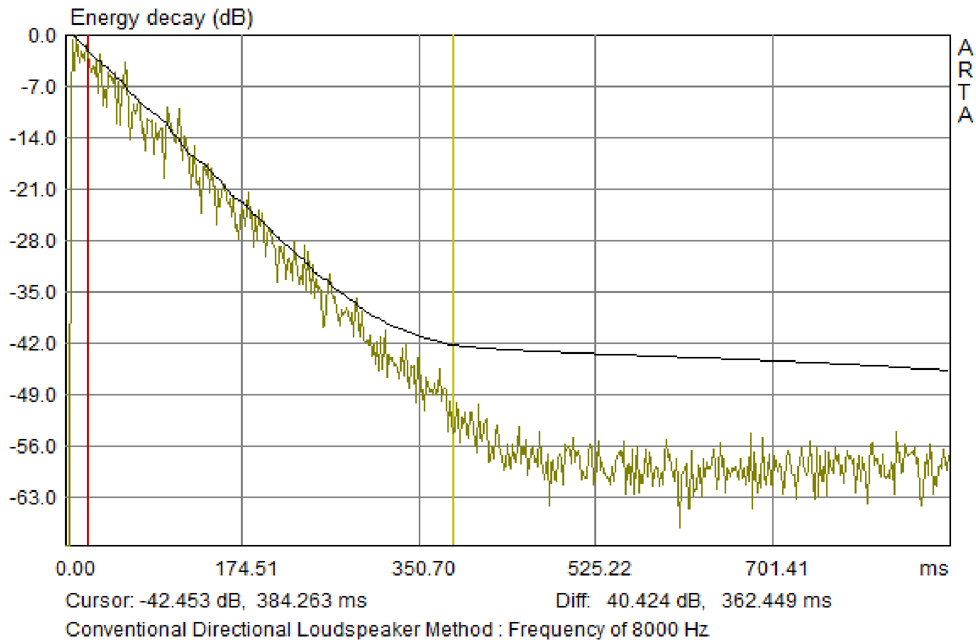

Figure 4-20: Measurement conducted with the CDL method for the frequency of 8000 Hz

Figure 4-19 and 4-20 present the measurements taken in the small room with the two methods for the frequency of the 8000 Hz. Figure 4-19 shows a reverberation time of 0.571 sec and figure 4-20 a reverberation time of 0.503 sec.

4.5.2 Medium sized room measurement results

Frequency of 62.5 Hz

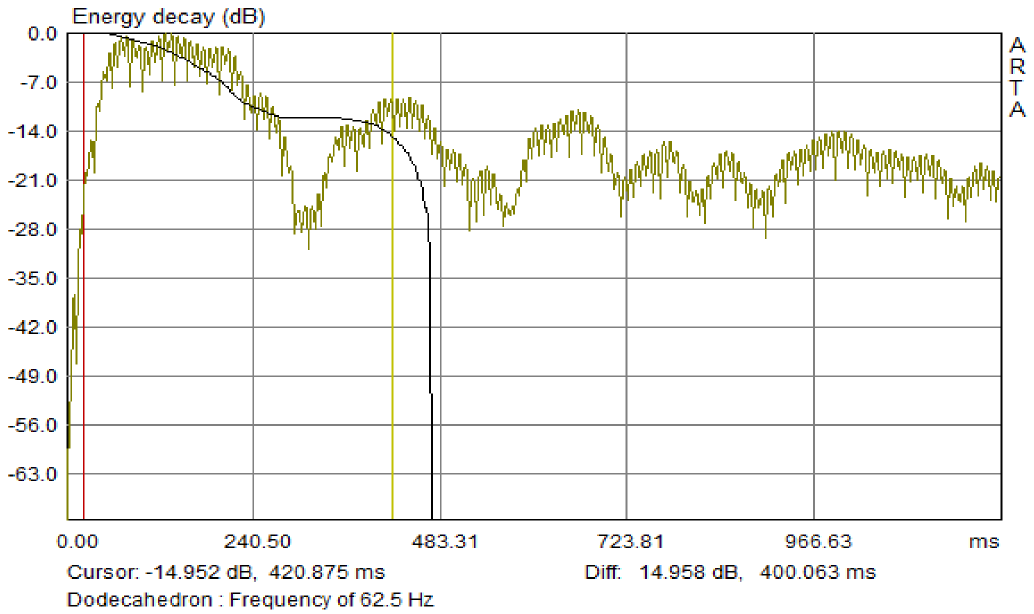

Figure 4-21: Measurement conducted with the Dodecahedron Loudspeaker for the frequency of 62.5Hz

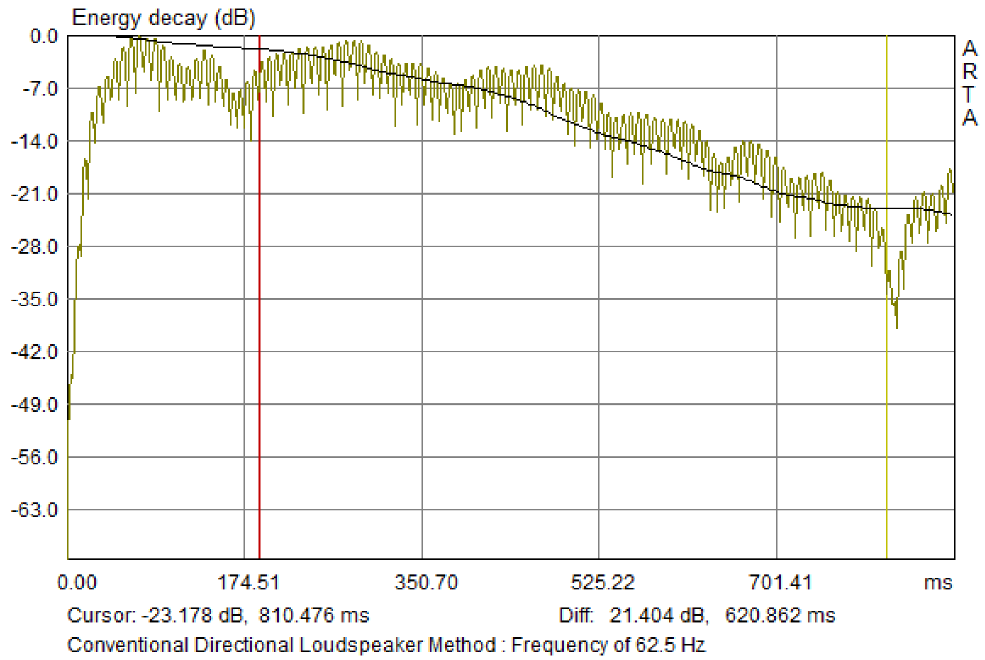

Figure 4-22: Measurement conducted with the CDL method for the frequency of 62.5 Hz

Figure 4-21 and 4-22 present the measurements conducted in the medium sized room with the two methods for the frequency of the 62.5 Hz. Figure 4-21 shows a reverberation time of 1.429 sec and figure 4-22 a reverberation time of 1.530 sec.

Frequency of 125 Hz

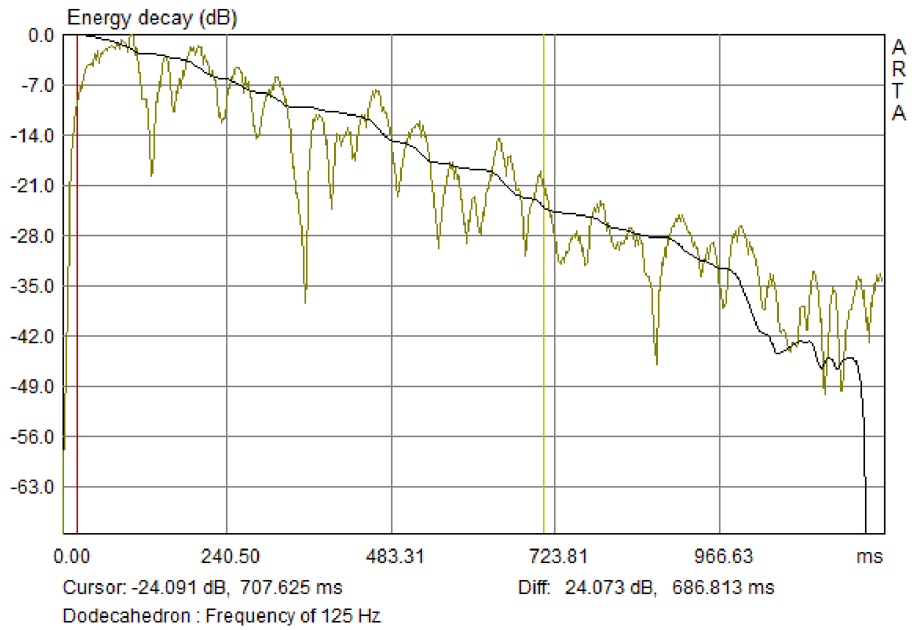

Figure 4-23: Measurement conducted with the Dodecahedron Loudspeaker for the frequency of 125 Hz

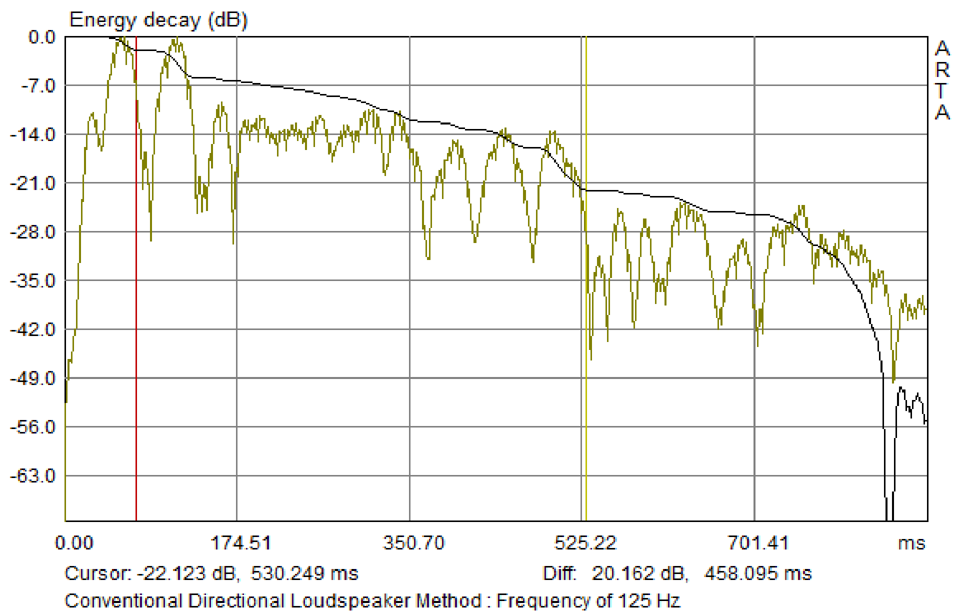

Figure 4-24: Measurement conducted with the CDL method for the frequency of 125 Hz

Figure 4-23 and 4-24 present the measurements taken in the medium sized room with the two methods for the frequency of the 125 Hz. Figure 4-23 shows a reverberation time of 1.729 sec and figure 4-24 a reverberation time of 1.689 sec.

Frequency of 250 Hz

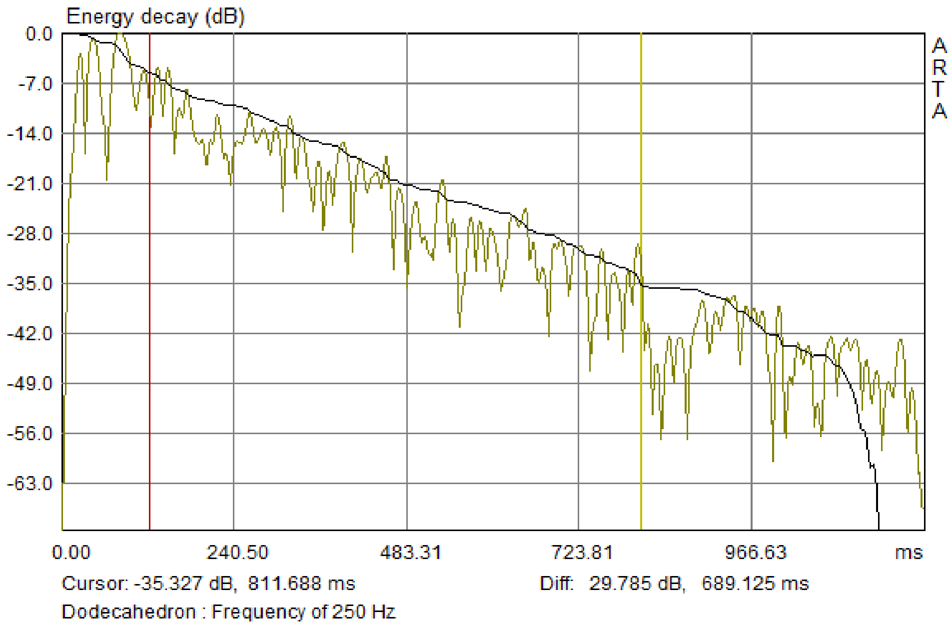

Figure 4-25: Measurement conducted with the Dodecahedron Loudspeaker for the frequency of 250 Hz

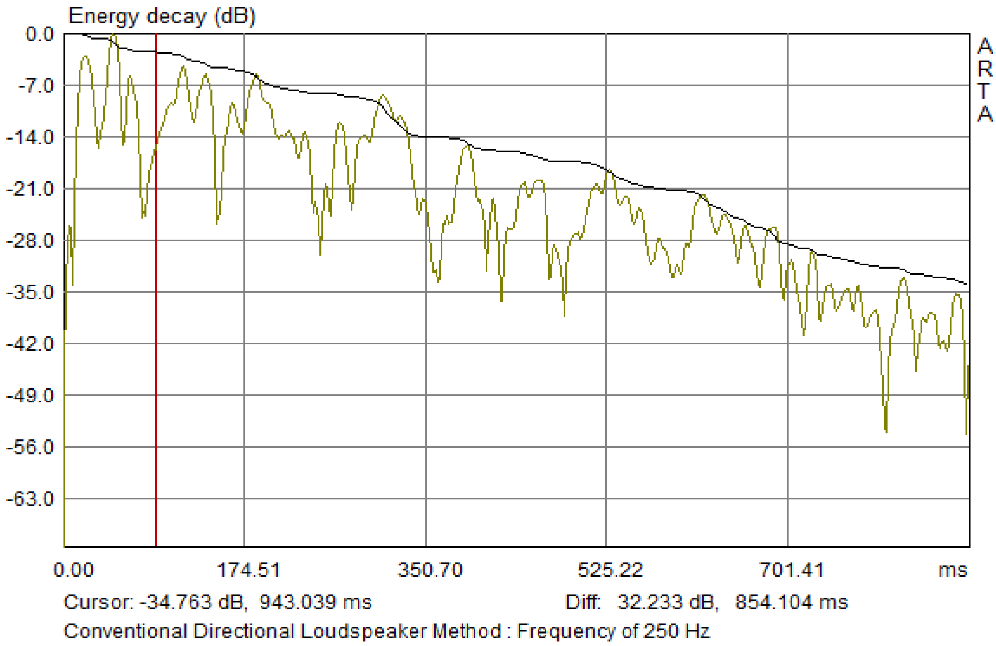

Figure 4-26: Measurement conducted with the CDL method for the frequency of 250 Hz

Figure 4-25 and 4-26 present the measurements taken in the medium sized room with the two methods for the frequency of the 250 Hz. Figure 4-25 shows a reverberation time of 1.468 sec and figure 4-26 a reverberation time of 1.463 sec.

Frequency of 500 Hz

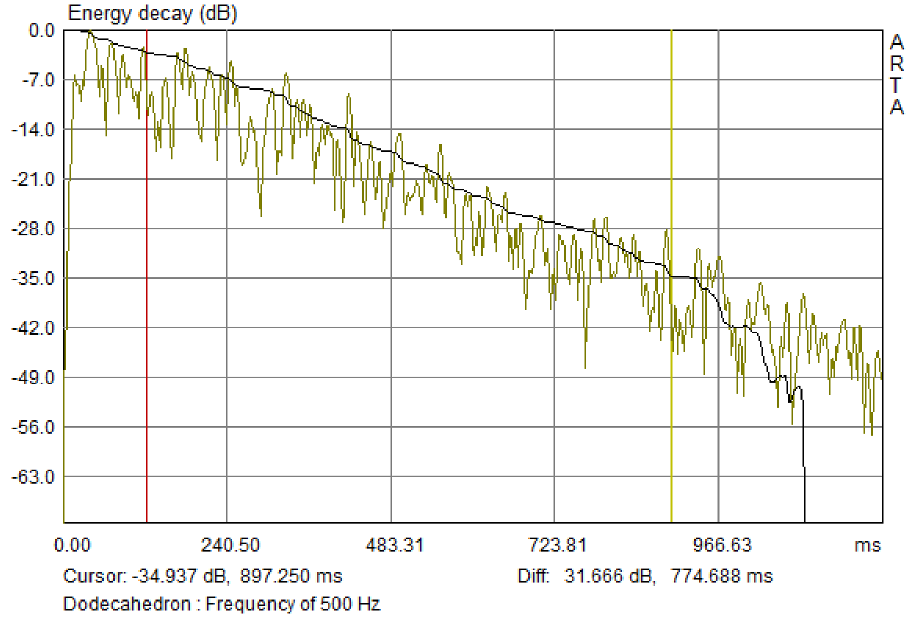

Figure 4-27: Measurement conducted with the Dodecahedron Loudspeaker for the frequency of 500 Hz

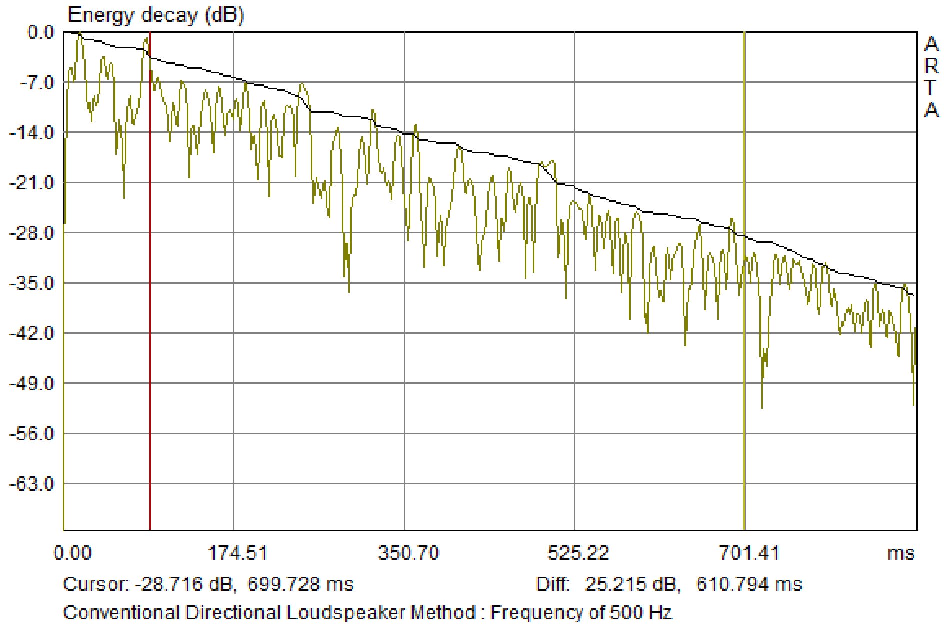

Figure 4-28: Measurement conducted with the CDL method for the frequency of 500 Hz

Figure 4-27 and 4-28 present the measurements taken in the medium sized room with the two methods for the frequency of the 500 Hz. Figure 4-27 shows a reverberation time of 1.443 sec and figure 4-28 a reverberation time of 1.426 sec.

Frequency of 1000 Hz

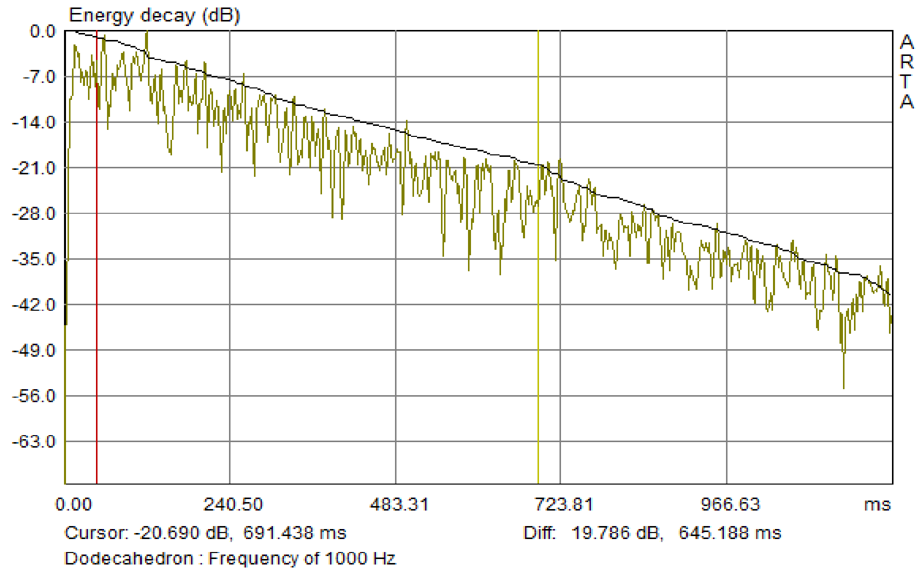

Figure 4-29: Measurement conducted with the Dodecahedron Loudspeaker for the frequency of 1000 Hz

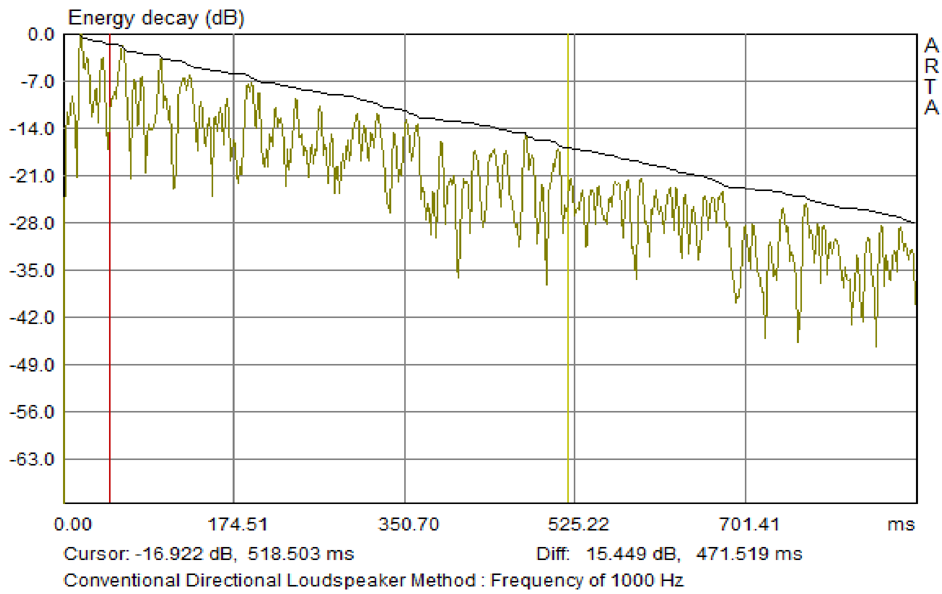

Figure 4-30: Measurement conducted with the CDL method for the frequency of 1000 Hz

Figure 4-29 and 4-30 present the measurements taken in the medium sized room with the two methods for the frequency of the 1000 Hz. Figure 4-29 shows a reverberation time of 1.936 sec and figure 4-30 a reverberation time of 1.925 sec.

Frequency of 2000 Hz

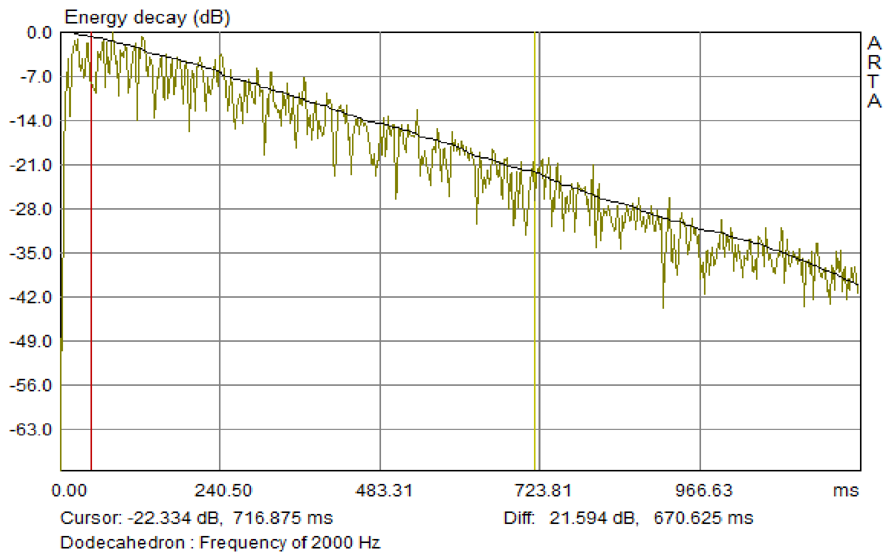

Figure 4-31: Measurement conducted with the Dodecahedron Loudspeaker for the frequency of 2000 Hz

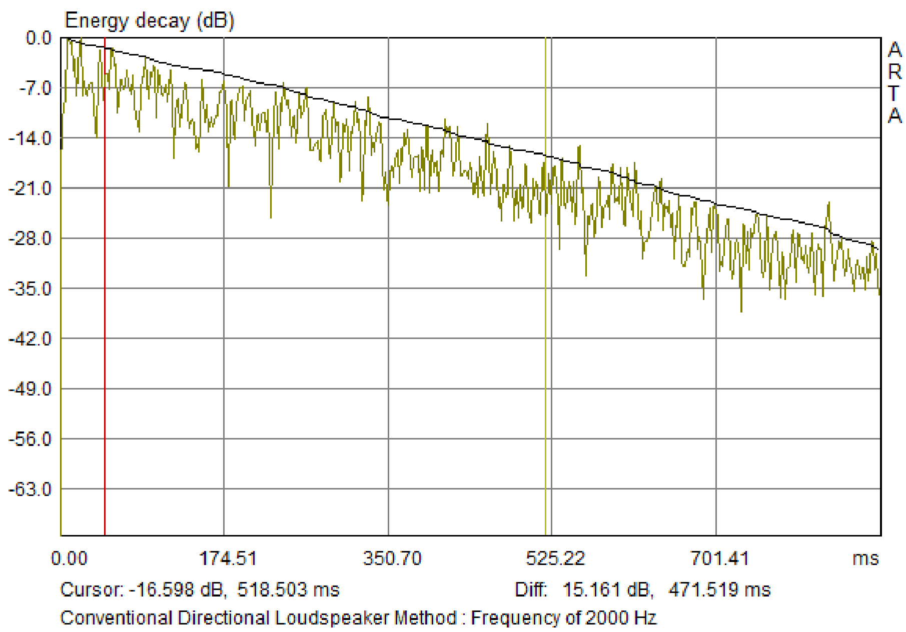

Figure 4-32: Measurement conducted with the CDL method for the frequency of 2000 Hz

Figure 4-31 and 4-32 present the measurements taken in the medium sized room with the two methods for the frequency of the 2000 Hz. Figure 4-31 shows a reverberation time of 1.813 sec and figure 4-32 a reverberation time of 1.836 sec.

Frequency of 4000 Hz

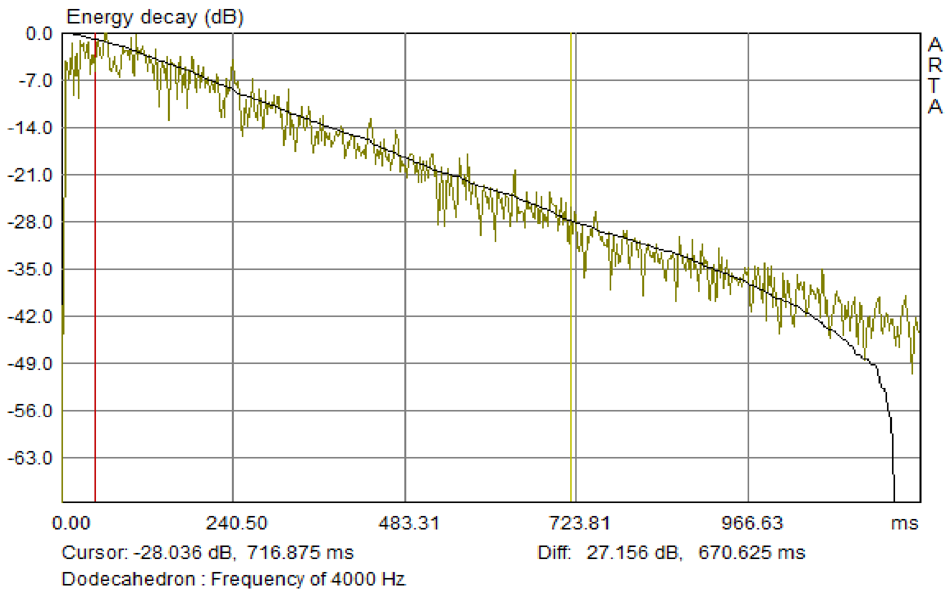

Figure 4-33: Measurement conducted with the Dodecahedron Loudspeaker for the frequency of 4000 Hz

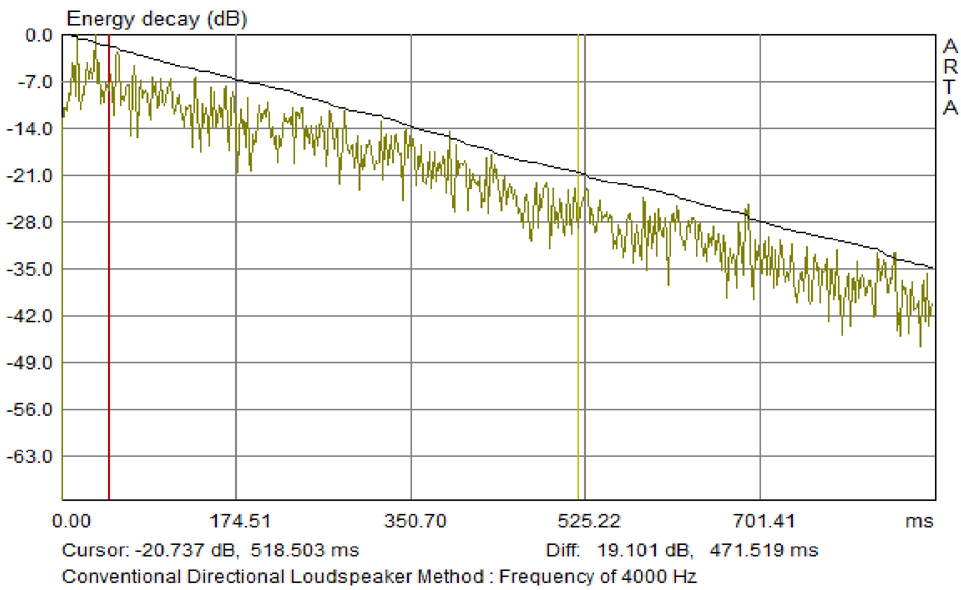

Figure 4-34: Measurement conducted with the CDL method for the frequency of 4000 Hz

Figure 4-33 and 4-34 present the measurements taken in the medium sized room with the two methods for the frequency of the 4000 Hz. Figure 4-33 shows a reverberation time of 1.465 sec and figure 4-34 a reverberation time of 1.466 sec.

Frequency of 8000 Hz

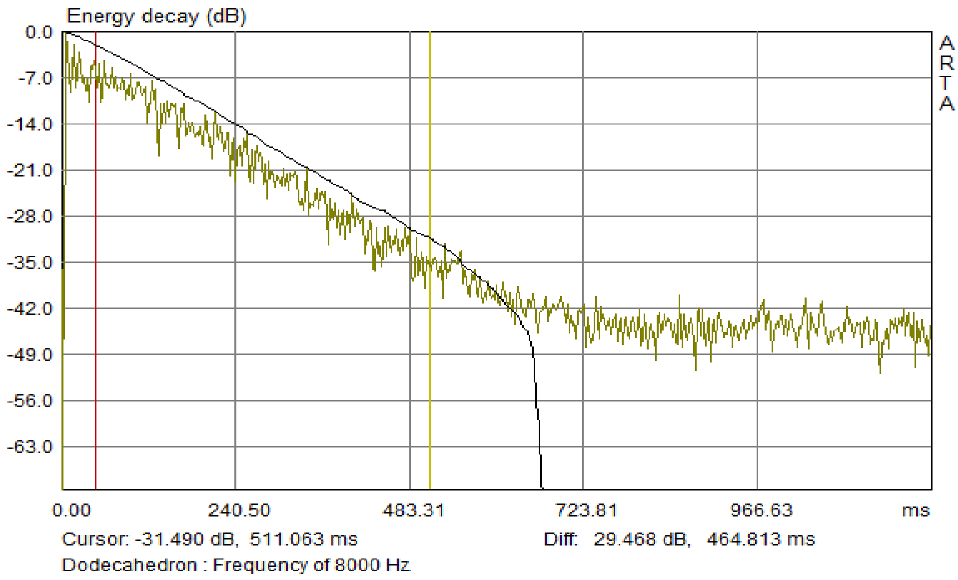

Figure 4-35: Measurement conducted with the Dodecahedron Loudspeaker for the frequency of 8000 Hz

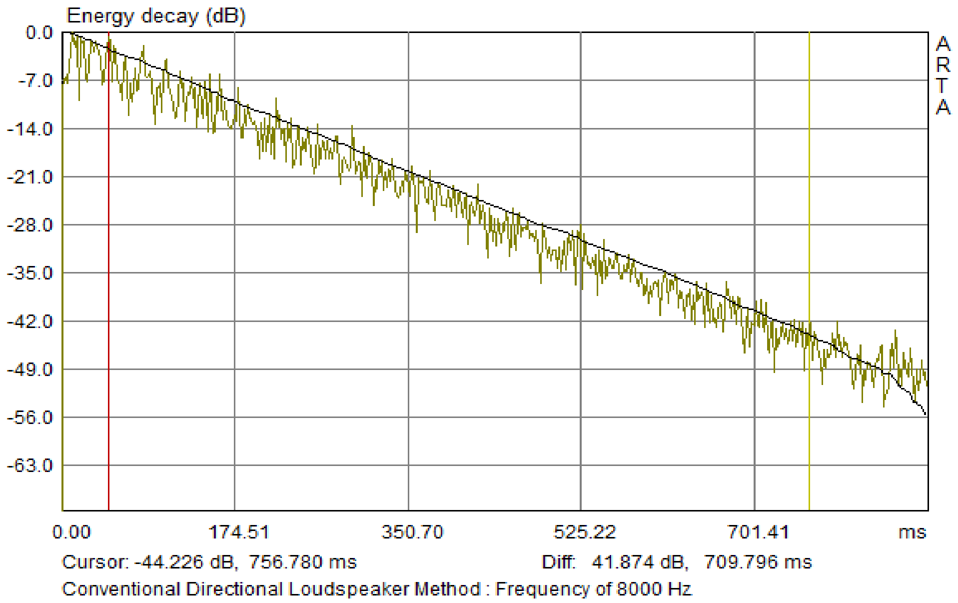

Figure 4-36: Measurement conducted with the CDL method for the frequency of 8000 Hz

Figure 4-35 and 4-36 present the measurements taken in the medium sized room with the two methods for the frequency of the 8000 Hz. Figure 4-35 shows a reverberation time of 0.923 sec and figure 4-36 a reverberation time of 1.029 sec.

4.6 Comparison of the results

4.6.1 Reverberation Time (RT_{60})

Figures 4.6-1 and 4.6-2, present the comparison between the results of the Reverberation Time measurements that took place in the small and the medium sized room of the Technological Educational Institute of Crete.

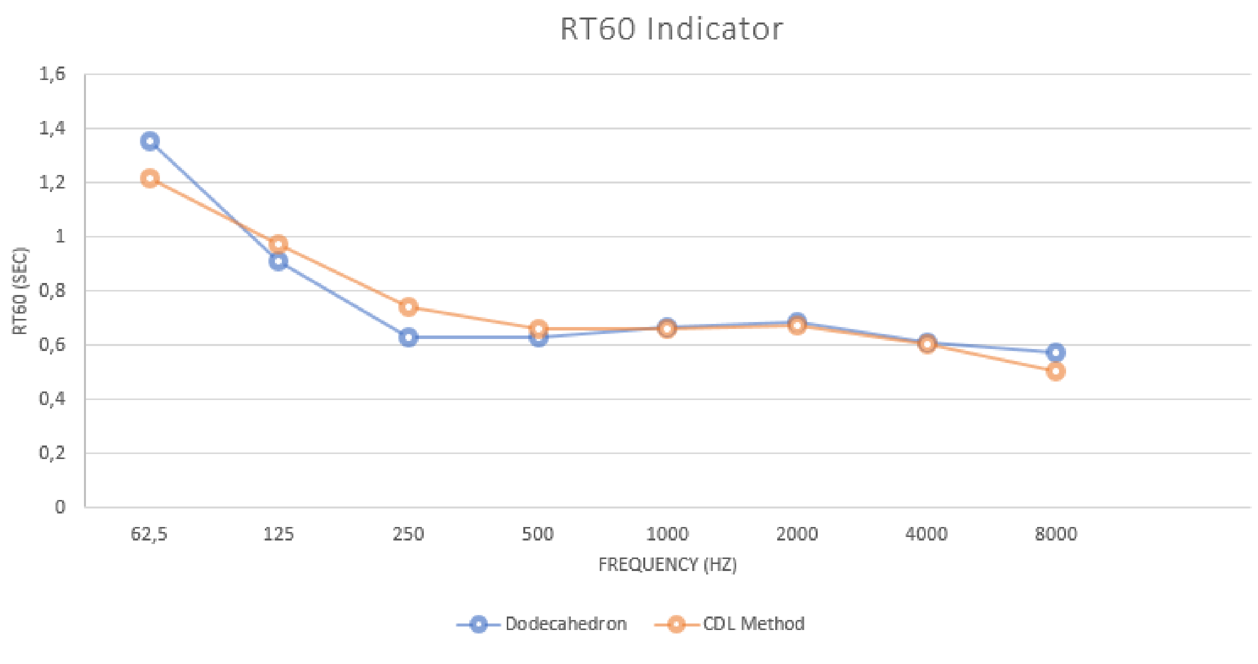

Figure 4.6-1: Figure presenting the Reverberation Time comparison in the small sized room.

As figure 4.6-1 shows, the blue line presents the measurement results for each frequency, of the dodecahedron loudspeaker, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. As one can easily notice, for the frequencies of 500, 1000, 2000, 4000 and 8000 Hz there is minimal divergence in the results, which proves that the new conventional directional loudspeaker method can be used as an alternative for measuring the reverberation time of a room without the need to use an expensive dodecahedral loudspeaker or any kind of specialized acoustic measurement equipment. As for the frequencies of the 62.5, 125 and 250 Hz there is some divergence which, according to the international bibliography, is not enough to alter the accuracy of the measurement.

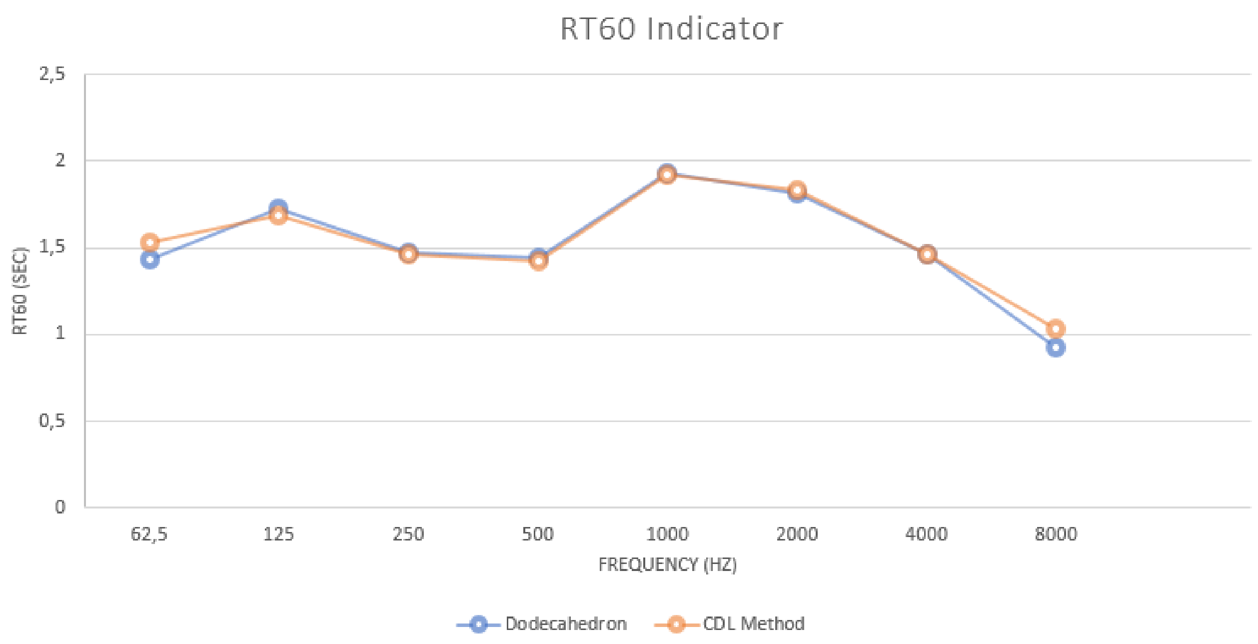

Figure 4.6-2: Figure presenting the Reverberation Time comparison in the medium sized room.

As figure 4.6-2 shows, the blue line presents the measurement results for each frequency, of the dodecahedron loudspeaker, while the orange one, presents, the measurements results of the new conventional directional loudspeaker method. For this medium sized room, the results of the two methods used, where identical with some minimal divergence in the frequencies of the 62.5, 500, 1000 and 8000 Hz. The results of the medium sized room show far better accuracy that the one of the small sized rooms something that clearly states that the conventional directional loudspeaker method can be used in a variety of spaces and rooms with the same and even greater accuracy.

4.6.2 T_{10} indicator

Figures 4.6-3 and 4.6-4, present the comparison between the results of the T_{10} indicator measurements that took place in the small and the medium sized room of the Technological Educational Institute of Crete.

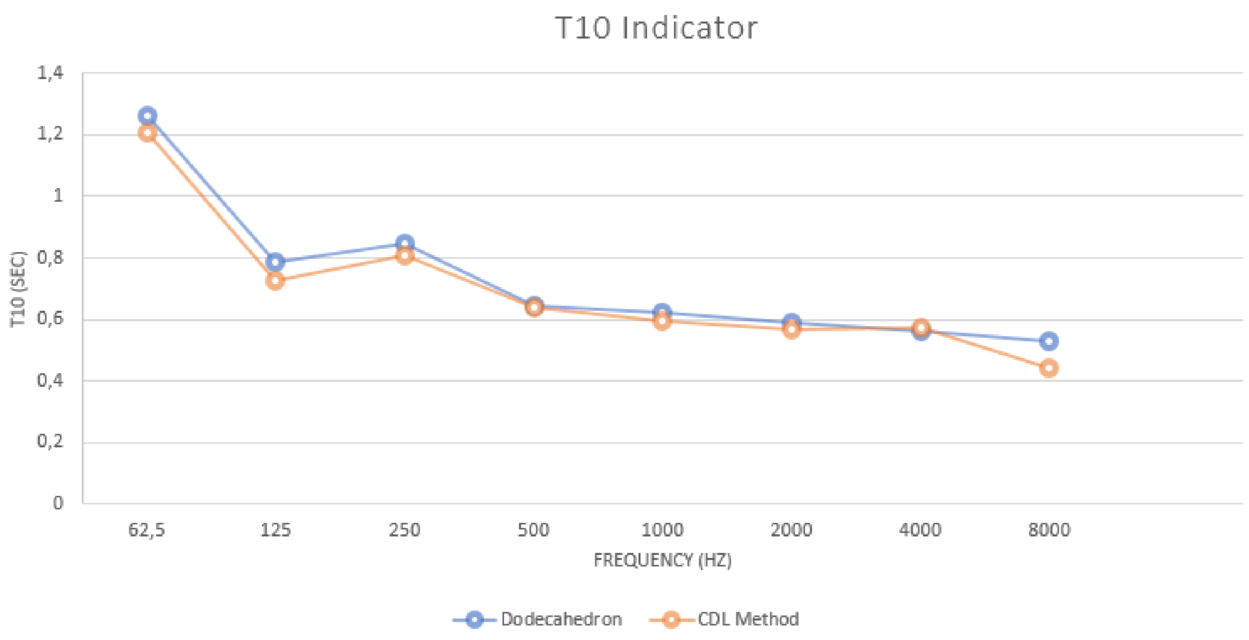

Figure 4.6-3: Figure presenting the T_{10} indicator comparison in the small sized room.

As figure 4.6-3 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this small sized room, the results of the two methods used, where identical with some minimal divergence in the frequencies of the 62.5, 125 and 250 Hz. The comparison of those two methods, prove that the T_{10} indicator can be measured with accuracy using the CDL method.

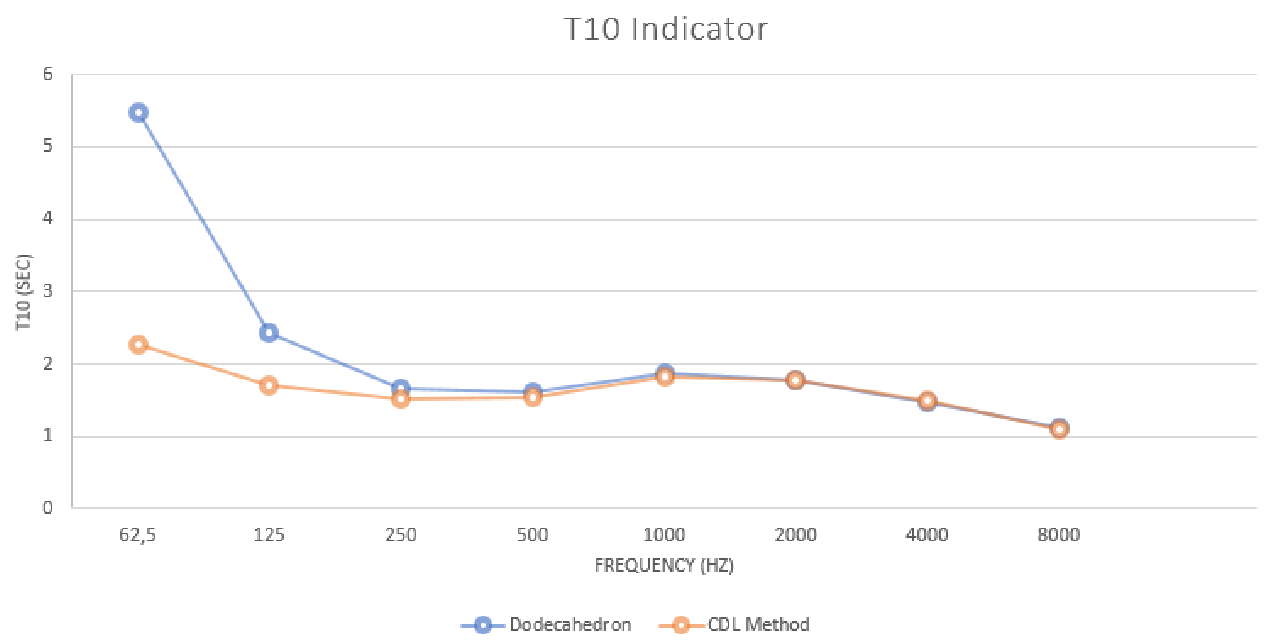

Figure 4.6-4: Figure presenting the T_{10} indicator comparison in the medium sized room.

As figure 4.6-4 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this medium sized room, the results of the two methods used, where identical with some minimal divergence in the frequencies of the 250 and 500 Hz. The frequencies of 62.5 and 125 Hz had a considerable difference, but those frequencies are so low that they cannot affect the overall accuracy of the method. The comparison of those two methods, prove that the T_{10} indicator can be measured with accuracy using the CDL method on the frequencies that the international bibliography suggest

4.6.3 T_{20} indicator

Figures 4.6-5 and 4.6-6, present the comparison between the results of the T_{20} indicator measurements that took place in the small and the medium sized room of the Technological Educational Institute of Crete.

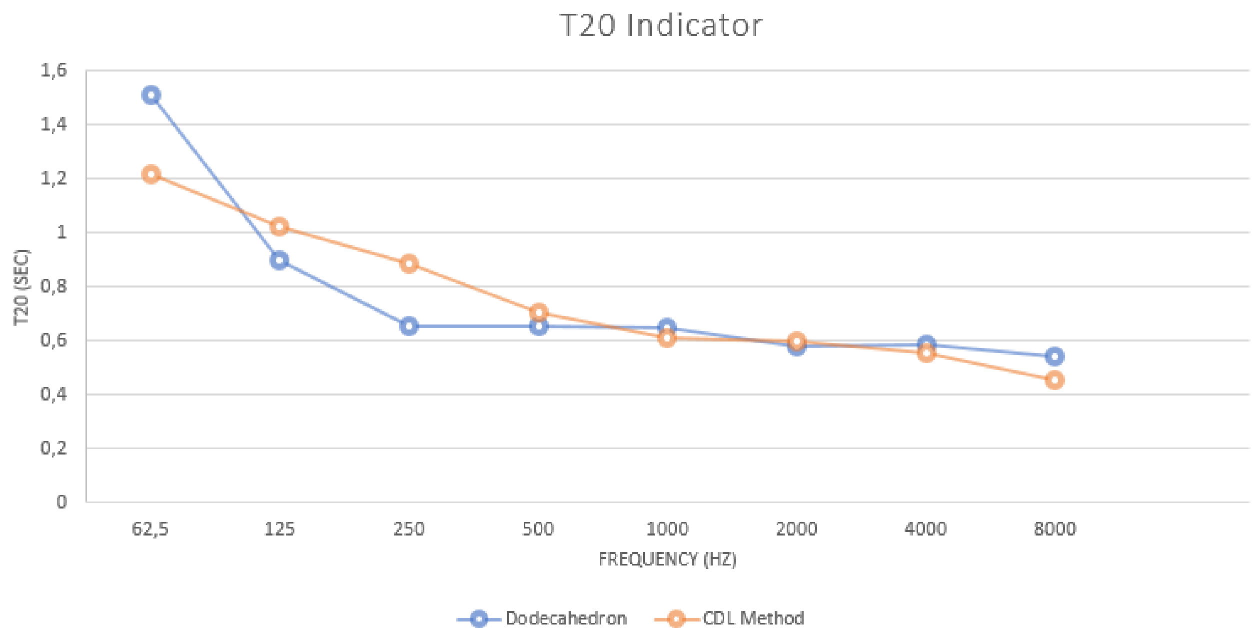

Figure 4.6-5: Figure presenting the T_{20} indicator comparison in the small sized room.

As figure 4.6-5 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this small sized room, the results of the two methods used, where identical with some minimal divergence in the frequencies of 500, 1000 and 8000 Hz. The frequencies of 62.5 and 125 Hz had a considerable difference, but those frequencies are so low that they cannot affect the overall accuracy of the method. The frequency of 250 Hz had a considerable difference between the two measurements. This may be a result of a miscalculation or a mistake in the measurement of the exact frequency due to the standing waves of the room. The comparison of those two methods, prove that the T_{20} indicator can be measured with accuracy using the CDL method on the frequencies that the international bibliography suggests, bearing in mind the different acoustic properties of each room.

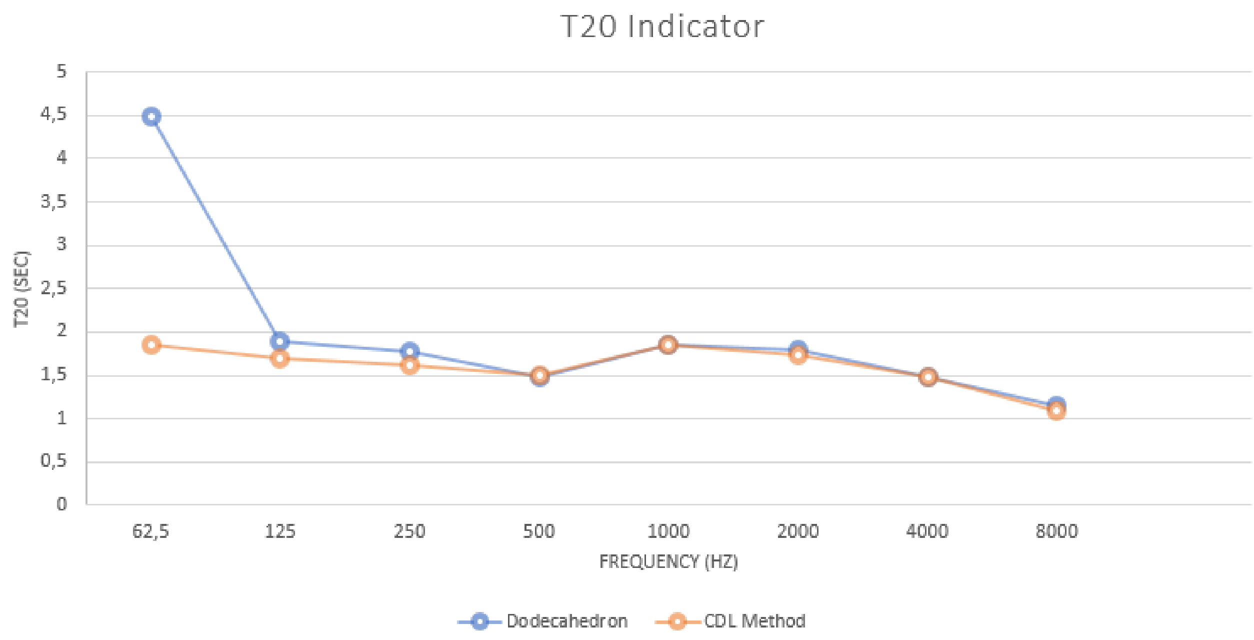

Figure 4.6-6: Figure presenting the T_{20} indicator comparison in the medium sized room.

As figure 4.6-6 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this medium sized room, the results of the two methods used, where identical with some minimal divergence in the frequencies of 125 and 250 Hz. The frequency of 62.5 Hz had a considerable difference between the two measurements, but the exact frequency is so low that it cannot affect the overall accuracy of the method. The comparison of those two methods, prove that the T_{20} indicator can be measured with accuracy using the CDL method on the frequencies that the international bibliography suggests.

4.6.4 T_{30} indicator

Figures 4.6-7 and 4.6-8, present the comparison between the results of the T_{30} indicator measurements that took place in the small and the medium sized room of the Technological Educational Institute of Crete.

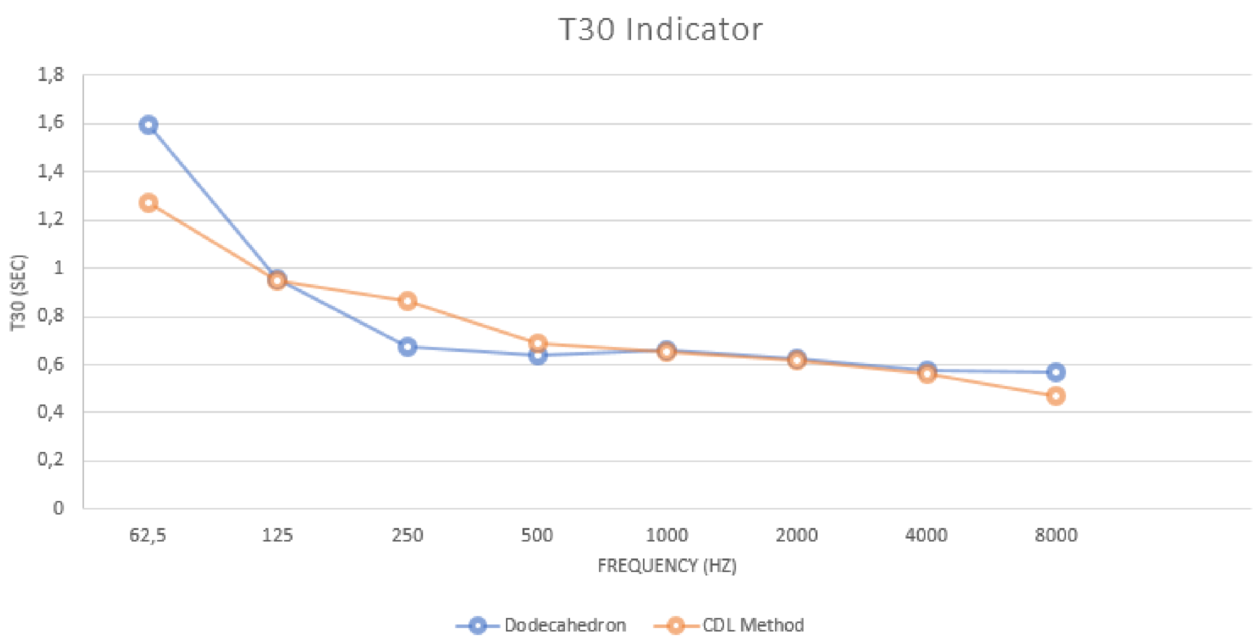

Figure 4.6-7: Figure presenting the T_{30} indicator comparison in the small sized room.

As figure 4.6-7 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this small sized room, the results of the two methods used, where identical with some minimal divergence in the frequencies of 500 and 8000 Hz. The frequency of 62.5 Hz had a considerable difference between the two measurements, but the exact frequency is so low that it cannot affect the overall accuracy of the method. The frequency of 250 Hz had a considerable difference between the two measurements. This may be a result of a miscalculation or a mistake in the measurement of the exact frequency due to the standing waves of the room. The comparison of those two methods, prove that the T_{30} indicator can be measured with accuracy using the CDL method on the frequencies that the international bibliography suggest, bearing in mind the different acoustic properties of each room.

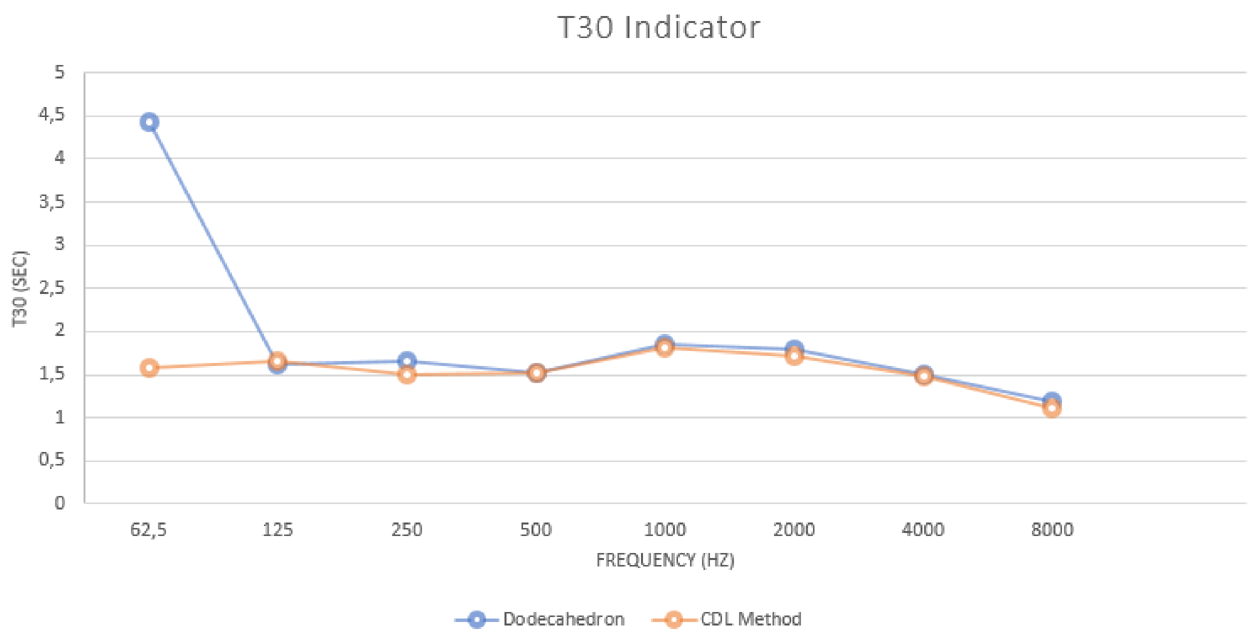

Figure 4.6-8: Figure presenting the T_{30} indicator comparison in the medium sized room.

As figure 4.6-8 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this medium sized room, the results of the two methods used, where identical with some minimal divergence in the frequency of 250 Hz. The frequency of 62.5 Hz had a considerable difference between the two measurements, but the exact frequency is so low that it cannot affect the overall accuracy of the method. The comparison of those two methods, prove that the T_{30} indicator can be measured with accuracy using the CDL method on the frequencies that the international bibliography suggests.

4.6.5 Early Decay Time (EDT)

Figures 4.6-9 and 4.6-10, present the comparison between the results of the Early Decay Time (EDT) indicator measurements that took place in the small and the medium sized room of the Technological Educational Institute of Crete.

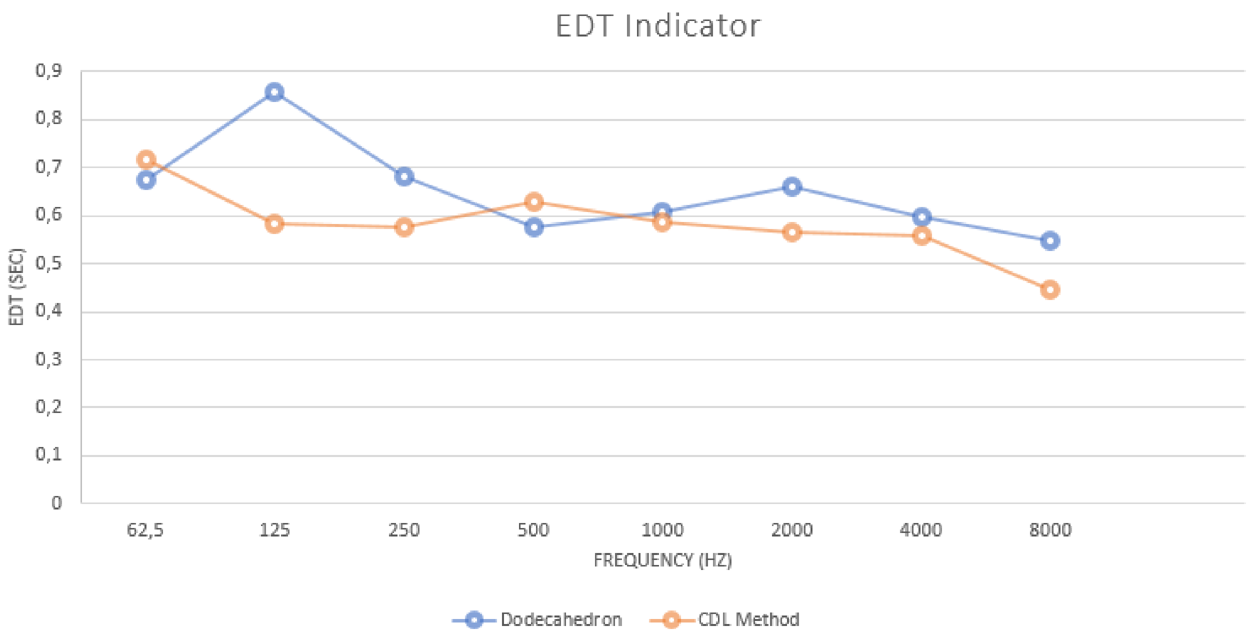

Figure 4.6-9: Figure presenting the EDT indicator comparison of the small sized room.

As figure 4.6-9 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this small sized room, the results of the two methods used, had considerable differences at most of the frequencies, except for those of 1000 and 4000 Hz. The frequencies of 125, 250, 2000 and 8000 Hz had the most considerable differences between the two measurements. The comparison of those two methods, prove that the EDT indicator cannot be measured with accuracy using the CDL method on the frequencies that the international bibliography suggests, and its use is not recommended on small rooms as far as the EDT indicator concerns.

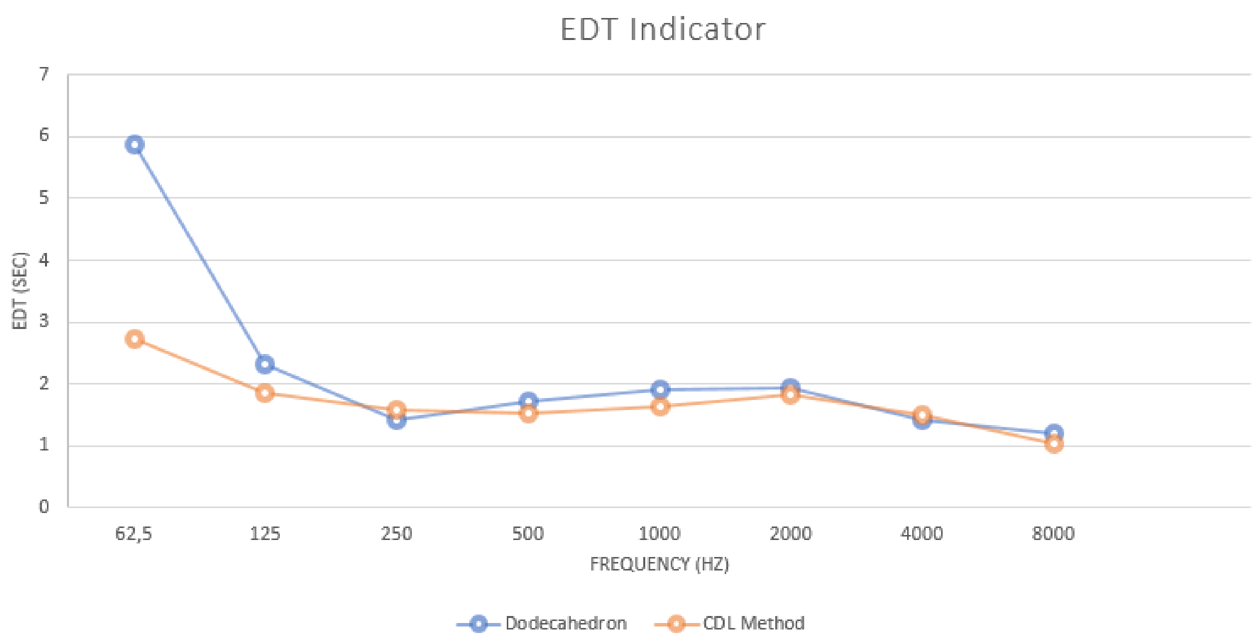

Figure 4.6-10: Figure presenting the EDT indicator comparison of the medium sized room.

As figure 4.6-10 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this medium sized room, the results of the two methods used, where identical with some minimal divergence in the frequency of 250, 500 and 1000 Hz. The frequency of 62.5 Hz had a considerable difference between the two measurements, but the exact frequency is so low that it cannot affect the overall accuracy of the method. The frequency of 125 Hz had some divergence, but it is not enough to affect the accuracy of the method. The comparison of those two methods, prove that the EDT indicator can be measured in medium sized rooms with accuracy and its use is recommended on such kind of rooms.

4.6.6 Clarity (C80)

Figures 4.6-11 and 4.6-12, present the comparison between the results of the Clarity (C80) indicator measurements that took place in the small and the medium sized room of the Technological Educational Institute of Crete.

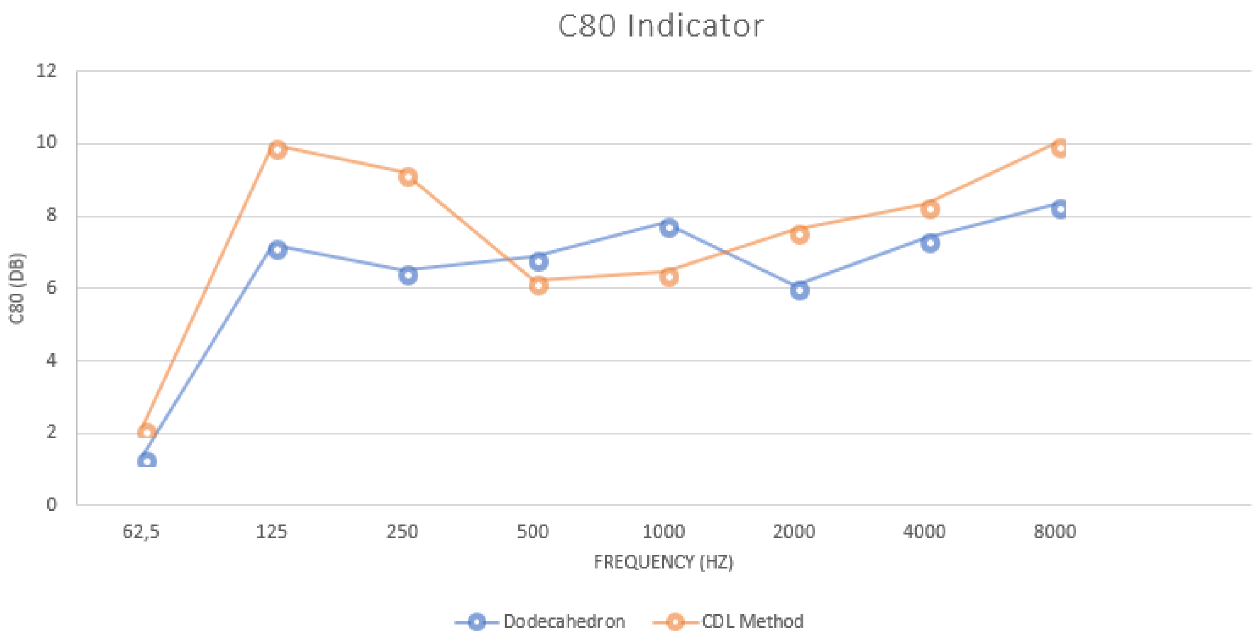

Figure 4.6-11: Figure presenting the C80 indicator comparison of the small sized room.

As figure 4.6-11 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this small sized room, the results of the two methods used, had considerable differences at most of the frequencies, except for those of 62.5, 500 and 4000 Hz. The frequencies of 125, 250, 1000, 2000 and 8000 Hz had the most considerable differences between the two measurements. The comparison of those two methods, prove that the C80 indicator cannot be measured with accuracy using the CDL method on the frequencies that the international bibliography suggests, and its use is not recommended on small sized rooms as far as the C80 indicator concerns.

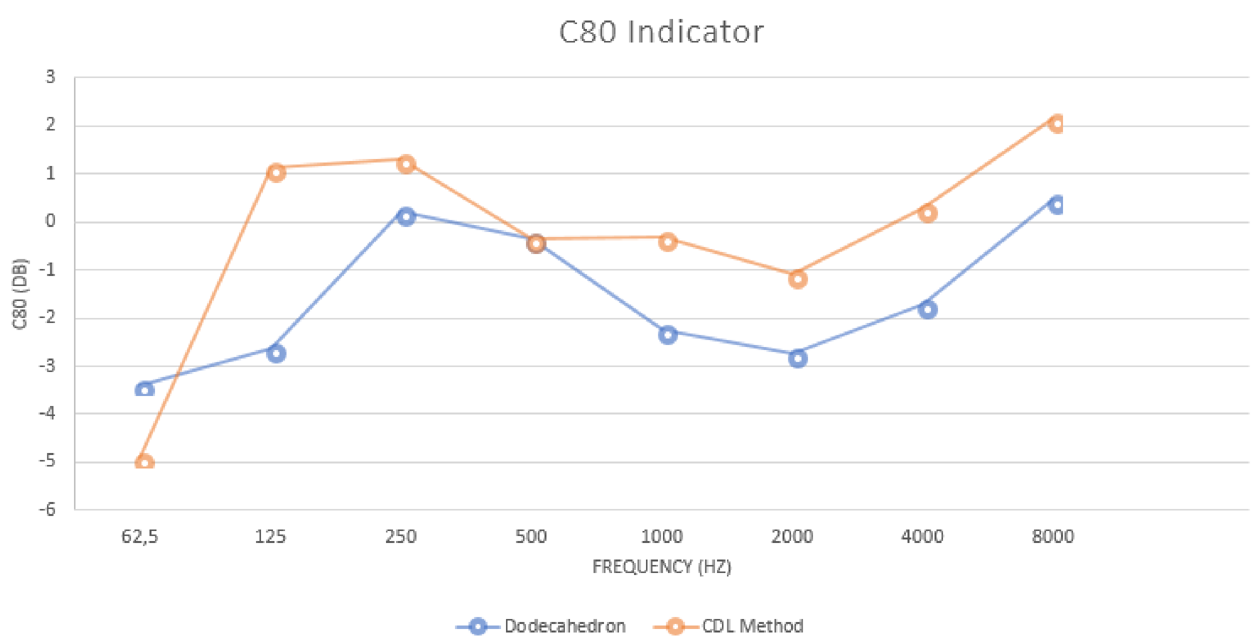

Figure 4.6-12: Figure presenting the C80 indicator comparison of the medium sized room

As figure 4.6-12 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this small sized room, the results of the two methods used, had considerable differences at most of the frequencies, except for the one of 500 Hz. The comparison of those two methods, prove that the C80 indicator cannot be measured with accuracy using the CDL method on the frequencies that the international bibliography suggests, and its use is not recommended on medium sized rooms as far as the C80 indicator concerns.

4.6.7 Clarity (C50)

Figures 4.6-13 and 4.6-14, present the comparison between the results of the Clarity (C50) indicator measurements that took place in the small and the medium sized room of the Technological Educational Institute of Crete.

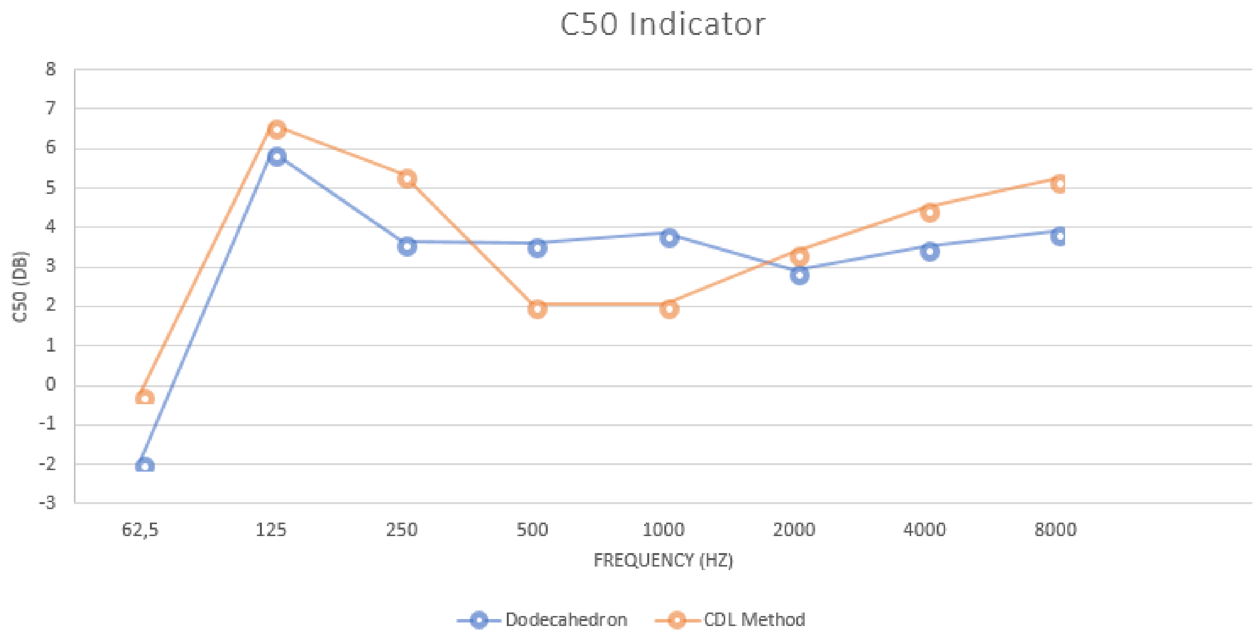

Figure 4.6-13: Figure presenting the C50 indicator comparison of the small sized room.

As figure 4.6-13 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this small sized room, the results of the two methods used, had some differences at most of the frequencies, except for those of 125, 2000 and 4000 Hz. All. The comparison of those two methods, prove that the C80 indicator cannot be measured with accuracy using the CDL method on the frequencies that the international bibliography suggests, and its use is not recommended on small sized rooms as far as the C80 indicator concerns.

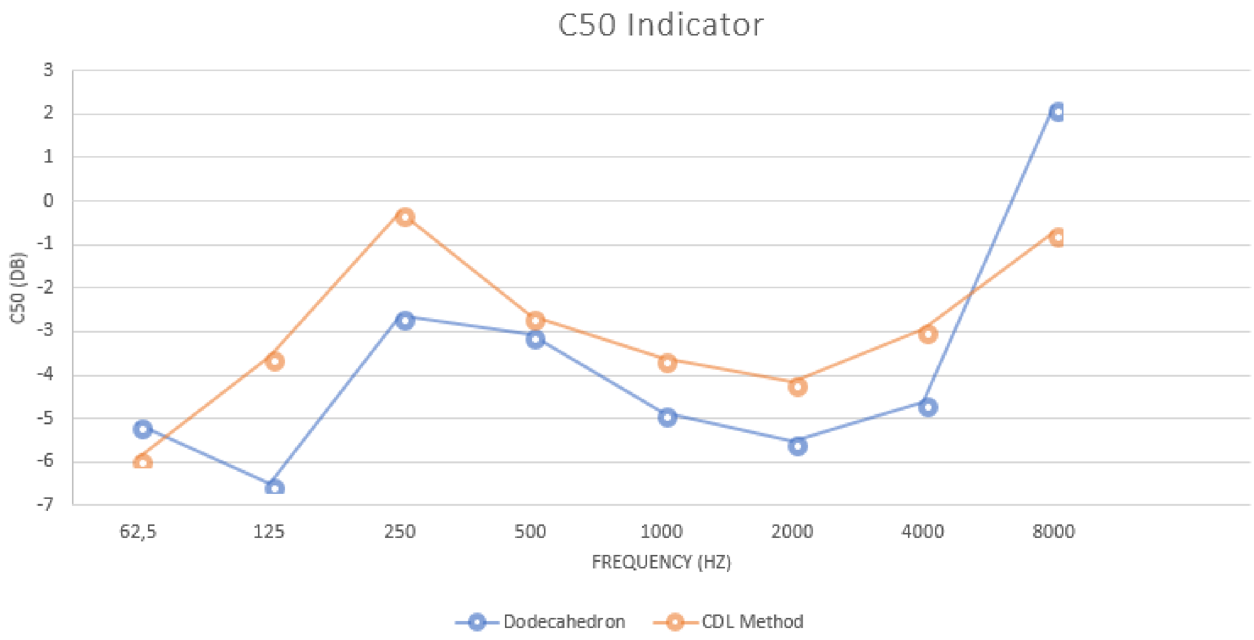

Figure 4.6-14: Figure presenting the C50 indicator comparison of the medium sized room.

As figure 4.6-14 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this medium sized room, the results of the two methods used, had considerable differences at most of the frequencies, except for the one of 500 Hz. The comparison of those two methods, prove that the C50 indicator cannot be measured with accuracy using the CDL method on the frequencies that the international bibliography suggests, and its use is not recommended on medium sized rooms as far as the C50 indicator concerns.

4.6.8 Definition (D50)

Figures 4.6-15 and 4.6-16, present the comparison between the results of the Definition (D50) indicator measurements that took place in the small and the medium sized room of the Technological Educational Institute of Crete.

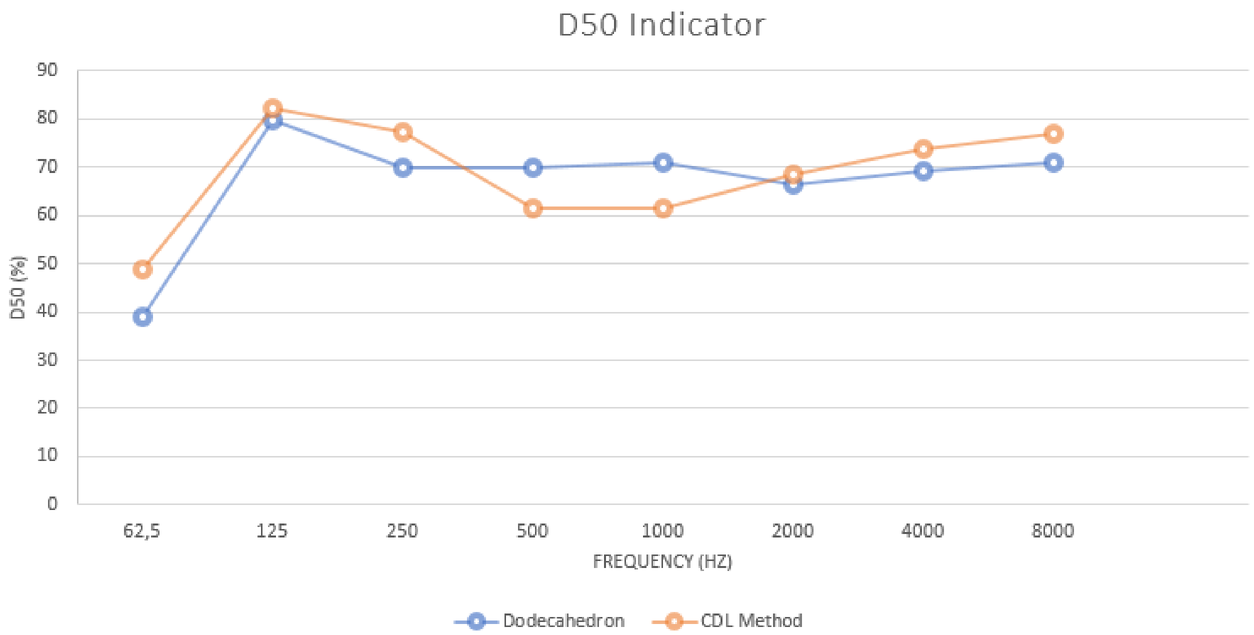

Figure 4.6-15: Figure presenting the D50 indicator comparison of the small sized room.

As figure 4.6-15 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this small sized room, the results of the two methods used, where identical with some divergence in the frequency of 500 and 1000 Hz. The comparison of those two methods, prove that the D50 indicator can be measured in small sized rooms with accuracy and its use is recommended on such kind of rooms.

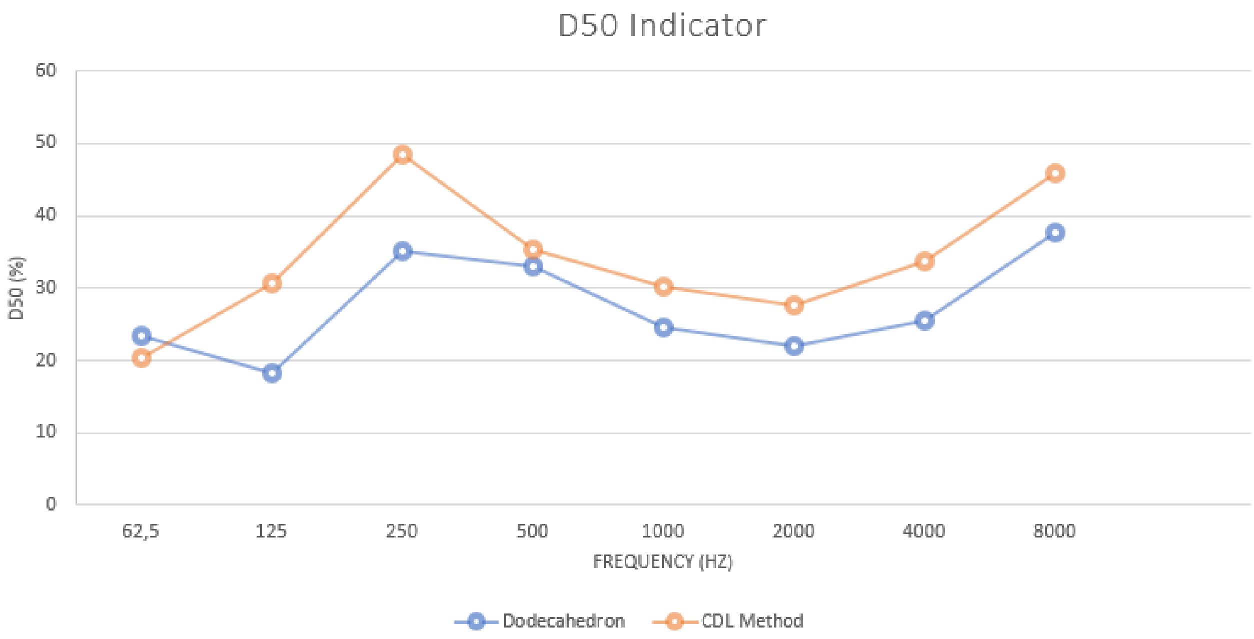

Figure 4.6-16: Figure presenting the D50 indicator comparison of the medium sized room

As figure 4.6-16 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this medium sized room, the results of the two methods used, had considerable differences at most of the frequencies, except for the one of 500 Hz. The comparison of those two methods, prove that the D50 indicator cannot be measured with accuracy using the CDL method on the frequencies that the international bibliography suggests, and its use is not recommended on medium sized rooms as far as the D50 indicator concerns.

4.6.9 Center Time (Ts)

Figures 4.6-17 and 4.6-18, present the comparison between the results of the Center Time (Ts) indicator measurements that took place in the small and the medium sized room of the Technological Educational Institute of Crete.

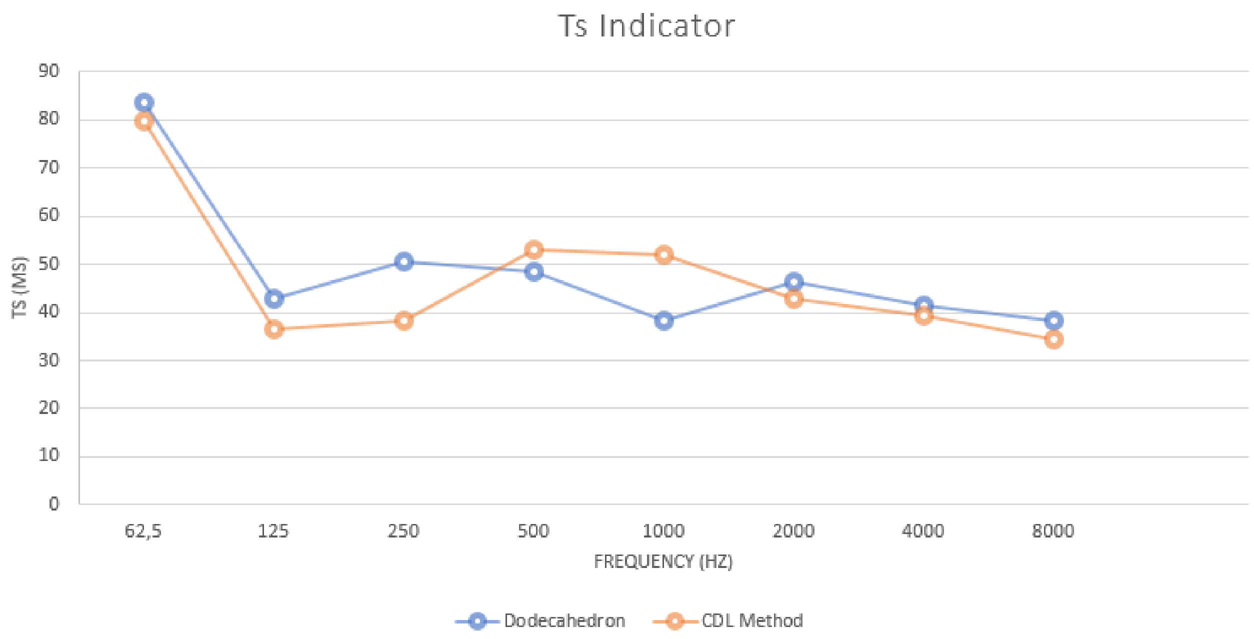

Figure 4.6-17: Figure presenting the Ts indicator comparison of the small sized room

As figure 4.6-17 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this small sized room, the results of the two methods used, where identical with some divergence in the frequency of 250 and 1000 Hz. The comparison of those two methods, prove that the Ts indicator can be measured with accuracy using the CDL method and its use is recommended on small sized rooms.

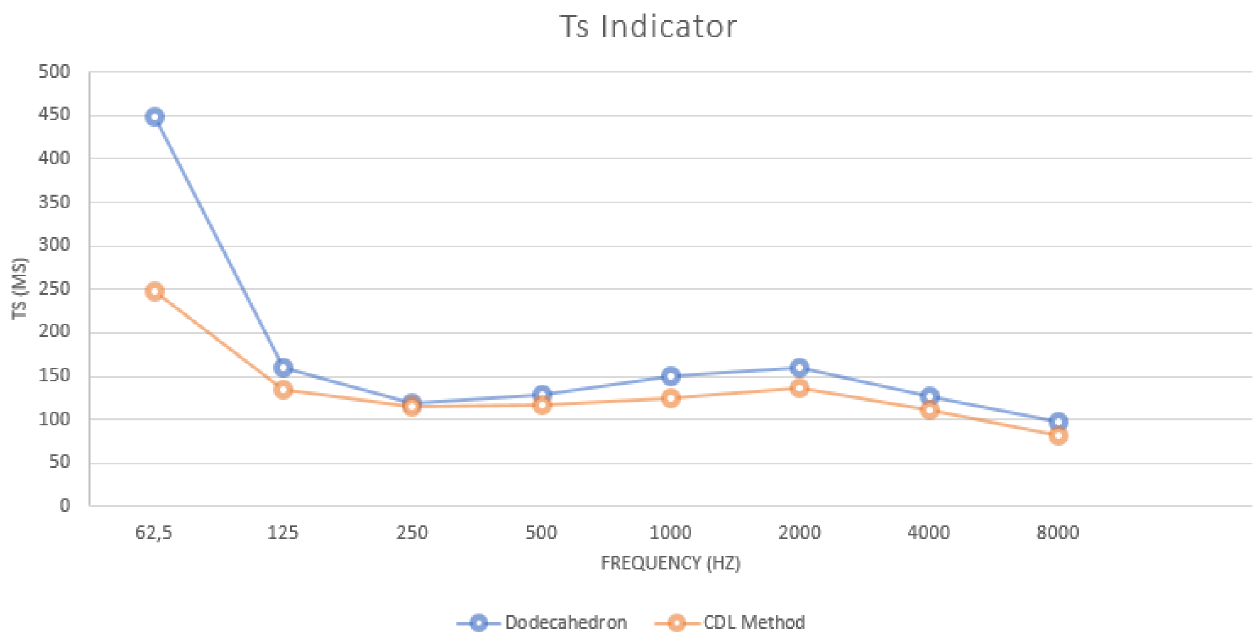

Figure 4.6-18: Figure presenting the Ts indicator comparison of the medium sized room

As figure 4.6-18 shows, the blue line presents the results of the dodecahedron loudspeaker measurement, in each frequency, while the orange one, presents, the measurement results of the new conventional directional loudspeaker method. For this medium sized room, the results of the two methods used, where identical with some divergence in the frequency of 62.5 Hz. The frequency of 62.5 Hz had a considerable difference between the two measurements, but the exact frequency is so low that it cannot affect the overall accuracy of the method. The comparison of those two methods, prove that the Ts indicator can be measured in medium sized rooms with accuracy and its use is recommended.

Chapter 5

Conclusion and Future work

5.1 Introduction

In this last chapter that follows, there is a general conclusion about the sustainability of the new conventional directional loudspeaker measurement method as well as the future developments of the method.

5.2 General conclusion

As evidenced by the previous chapters, the new conventional directional loudspeaker method is a very accurate method to measure the acoustic parameter of the Reverberation time in various sized rooms, without the need of expensive equipment such as the dodecahedral loudspeaker. By minimizing the equipment needed to conduct an acoustic research, we achieved a major cost reduction in the whole process. This dissertation, provides all the required theoretical and practical knowledge for every acoustic engineer to achieve accurate and costless measurements with the use of the conventional directional loudspeaker measurement method.

5.3 Sustainability of the method

The conventional directional loudspeaker method can accurately measure the Reverberation time in all kind of rooms, with the same, or with a minimal divergence in accuracy, as of those conducted with the use of an omnidirectional dodecahedron loudspeaker.

5.4 Future work

With the growth of population and buildings, the near future holds a great deal for the science of acoustics. With that being said, having an accurate method without needing a tremendous amount of finance to conduct acoustic researches is of vital meaning. Soon, this method can be the starting point for a lot of new ideas. One of those can be the testing of this method in the free field and in outside spaces so that someone can prove that this method does not only work for indoor spaces but also for exterior.

Appendix A

Tables presenting the acoustic indicators

Frequency (Hz)	T_{10} (sec)	T_{20} (sec)	T_{30} (sec)	RT_{60} (sec)	EDT (sec)	C_{80} (dB)	C_{50} (dB)	D_{50} (%)	T_s (ms)
62.5	1.262	1.509	1.594	1.357	0.675	1.37	-1.91	39.1	83.6
125	0.785	0.900	0.958	0.911	0.856	7.22	5.92	79.6	42.7
250	0.846	0.656	0.672	0.633	0.681	6.51	3.65	69.8	50.4
500	0.647	0.654	0.636	0.628	0.575	6.90	3.62	69.7	48.3
1000	0.624	0.649	0.658	0.666	0.608	7.81	3.88	70.9	38.3
2000	0.590	0.580	0.626	0.684	0.660	6.10	2.93	66.2	46.5
4000	0.565	0.585	0.579	0.611	0.596	7.38	3.51	69.1	41.5
8000	0.532	0.543	0.571	0.571	0.547	8.32	3.90	71.0	38.3

Table A-1: Acoustic Indicators as measured in the small sized room with the dodecahedron loudspeaker.

Frequency (Hz)	T_{10} (sec)	T_{20} (sec)	T_{30} (sec)	RT_{60} (sec)	EDT (sec)	C_{80} (dB)	C_{50} (dB)	D_{50} (%)	T_s (ms)
62.5	1.208	1.216	1.273	1.215	0.716	2.15	-0.21	48.7	79.8
125	0.727	1.022	0.945	0.972	0.583	9.97	6.60	82.0	36.4
250	0.808	0.889	0.862	0.742	0.575	9.22	5.35	77.4	38.3
500	0.640	0.704	0.691	0.664	0.630	6.24	2.05	61.5	52.9
1000	0.593	0.611	0.650	0.660	0.587	6.47	2.05	61.5	52.1
2000	0.566	0.602	0.621	0.674	0.564	7.62	3.40	68.6	42.7
4000	0.573	0.557	0.561	0.605	0.558	8.32	4.53	73.9	39.3
8000	0.444	0.456	0.471	0.503	0.447	10.0	5.26	77.0	34.5

Table A-2: Acoustic Indicators as measured in the small sized room with the CDL method.

Frequency (Hz)	T_{10} (sec)	T_{20} (sec)	T_{30} (sec)	RT_{60} (sec)	EDT (sec)	C_{80} (dB)	C_{50} (dB)	D_{50} (%)	T_s (ms)
62.5	5.477	4.748	4.436	1.429	5.884	-3.39	-5.14	23.4	447.8
125	2.434	1.886	1.619	1.729	2.308	-2.64	-6.51	18.2	160.3
250	1.657	1.770	1.661	1.468	1.428	0.21	-2.65	35.1	118.3
500	1.608	1.480	1.520	1.443	1.709	-0.33	-3.08	32.9	128.8
1000	1.861	1.858	1.854	1.936	1.904	-2.25	-4.86	24.6	150.3
2000	1.779	1.799	1.788	1.813	1.927	-2.73	-5.51	21.9	159.0
4000	1.478	1.475	1.502	1.465	1.424	-1.71	-4.62	25.6	125.9
8000	1.119	1.151	1.192	0.923	1.187	0.47	2.15	37.8	97.5

Table A-3: Acoustic Indicators as measured in the medium sized room with the dodecahedron loudspeaker.

Frequency (Hz)	T_{10} (sec)	T_{20} (sec)	T_{30} (sec)	RT_{60} (sec)	EDT (sec)	C_{80} (dB)	C_{50} (dB)	D_{50} (%)	T_s (ms)
62.5	2.274	1.851	1.585	1.530	2.718	-4.93	-5.90	20.4	248.4
125	1.713	1.705	1.650	1.689	1.847	1.14	-3.55	30.6	133.9
250	1.510	1.624	1.508	1.463	1.591	1.31	-0.27	48.4	114.4
500	1.551	1.510	1.530	1.426	1.541	-0.33	-2.63	35.3	116.9
1000	1.833	1.849	1.819	1.925	1.634	-0.31	-3.60	30.3	124.3
2000	1.772	1.740	1.708	1.836	1.818	-1.07	-4.17	27.7	136.5
4000	1.486	1.472	1.478	1.466	1.498	0.27	-2.94	33.6	111.1
8000	1.108	1.097	1.117	1.029	1.049	2.13	-0.73	45.8	81.9

Table A-4: Acoustic Indicators as measured in the medium sized room with the CDL method.

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