DIPLOMARBEIT

Acoustical Performance of Multi-purpose Halls

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KURZFASSUNG

Da sie als eine der wichtigsten Treffpunkte in Städten dienen, haben kulturelle Veranstaltungsorte über Jahrhunderte eine bedeutende Aufmerksamkeit erhalten. Eine der wichtigsten Anforderungen, um ihren Zweck zu erfüllen, ist eine hervorragende Akustik zu gewährleisten. Dies gilt besonders im Bereich der darstellenden Künste.

In der Vergangenheit waren die meisten kulturellen Veranstaltungsorte funktionsbezogen (beispielsweise Konzerthallen, Theater oder Opernhäuser). Heute, mit ansteigenden Konstruktions- und Organisationskosten sowie der erhöhten urbanen Verdichtung, bekommt das Konzept eines Multifunktionsgebäude stets eine höhere Relevanz. Die steigende Nachfrage nach multifunktionalen Räumen führt ebenfalls zu verschiedensten Forschungstätigkeiten in diesem Bereich.

Diese Studie untersucht das akustische Verhalten von vier Multifunktionshallen in Wien. Es wurden Messungen vor Ort durchgeführt, sowie digitale Simulationsmodelle erstellt. Die Kalibrierung der Simulationen wurde mehrmals durchgeführt bis die Ergebnisse möglichst nahe mit den Messungen übereinstimmen. Diese Studie gibt einen Überblick über das akustische Verhalten der vier ausgewählten Multifunktionshallen. Der Kalibrierungs-Prozesses wird detailliert beschrieben, gefolgt von einer Diskussion der Ergebnisse und Vorschlägen für weitere Forschungsaktivitäten in diesem Bereich.

Keywords

Bauakustik, Mehrzweckhallen, Nachhallzeit, Schallausbreitung, Schalldruckpegel, Raumakustik, Raumakustische Simulation, Odeon

ABSTRACT

Cultural venues, as some of the most important scenes of a city, have historically received due attention in architectural scholarship. One of the most important requirements for these venues to achieve their purpose, especially when it comes to performing arts, is excellent acoustics. This is directly related to room acoustics, which represents a founding part of architectural acoustics and one of the most complex branches in the field of sound.

In the past, almost all of the cultural venues were purpose-based, i.e. concert halls, theaters, or opera houses. Nowadays, as the cost of construction and organization increase and cities become denser, the concept of multi-purpose halls becomes more and more relevant. The increasing demand of multi-purpose halls has been followed with an increase in the field of research. This study in particular deals with the acoustical performance of four multi-purpose halls located in Vienna. On-site measurements were performed and models of the halls with best geometry and material approximation were made. Furthermore, calibration of the simulations was performed until the simulations have come to a satisfactory agreement with the on-site measurements. An overview of the process of calibration is made which gives an insight and solutions into the possible faults that may bring inconsistency when attempting to create a model for acoustical assessment of an existing room. Finally this contribution provides an overview of the acoustical performance of the four case studies, following a discussion and suggestions of possible further research.

Keywords

Architectural acoustics, Multi-purpose halls, Acoustic performance, Reverberation Time, Sound distribution, Sound pressure level, Room acoustics, Room acoustic simulation, Odeon

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CONTENTS

1 INTRODUCTION

1.1 Overview

Architectural acoustics has shown its importance since the days of ancient Greece, when many of the world's most fascinating masterpieces were built with such careful mastery in order to achieve acoustical greatness. It is by no means a miracle the fact that a performing actor in the ancient theatre of Epidaurus can, on a windless day, clearly be heard even from the back rows, which are almost 60 meters away from the scene. It is actually a carefully constructed setting which uses the seat rows as a filter for low frequency sounds in order to reduce noise, as well as using second order diffracted sounds for better reception of sound (Declercq and Dekeyser, 2007). In fact, this represents the lengths that the architects would go to reach the main requirement for a theatre performance to be fully experienced – clarity.

This exquisiteness did not stop there and went on to flourish especially with sacred compositions performed in cathedrals and later on with classical music in concert halls. There has been music composed based on the properties of big, reverberant cathedrals, and there have been concert and opera halls designed specifically and based on the requirements of classical music. Therefore, it is safe to assume that sound and architecture have been completing each-other for a very long time.

It is no wonder that nowadays architecture has to keep up with the vast and versatile requirements of modern society. Purpose-built halls such as concert halls or opera houses which serve for one purpose only are becoming rare due to the construction and organizational costs, as well as the increasing density of cities. Therefore more and more venues are being designed in order to be used with more than solely one purpose.

The main scope of this work was to analyse the complexity of the concept of a multi-purpose hall with regards to the different acoustical requirements for each of the defined performances, focusing on the RT (Reverberation Time) and SPL (Sound Pressure Level) as two of the main relevant acoustic performance indicators. Measurements were set up in four case studies, all of which located in Vienna. The workflow included setting up an omni-directional speaker and a grid of receivers in each of the unoccupied halls and getting the real output of RT, SPL and other relevant energy parameters. Following the measurements was the modelling of these four halls with best possible geometry and first material approximations and simulation of the models in the room acoustic software Odeon (ODEON, 2011). The materials used in the simulation were partially part of the material library provided by Odeon and partially based on literature research. After the first simulations the simulated results were compared to the on-site measurement results after which the validity of the simulated model was able to be assessed and accordingly calibrated. The findings give an overview on the acoustical performance of the four case studies as well as the reliability of using virtual acoustics to extract real performance indicators. Finally an overview of the most relevant results of this contribution is given following a discussion and suggestions on potential future research.

1.2 Motivation

It is undeniable that cultural venues are among the most important buildings of a city. This is the reason why there is continuously on-going attention and research on buildings such as the National Theatre of Vienna or the Vienna State Opera. Even though constructing such grandiose and fascinating venues is unquestionably a complex undertaking, the one straight-forward part of it is that their purpose is very specific. As Holden (2016) puts it, the acoustics of a space must be determined by the *particular* type of the performance that utilizes the space. It is therefore potentially more difficult to design an acoustically excellent space that will be versatile and serve for several different purposes instead of a single one.

The motivation behind this study is to make assessment on halls which remain largely understudied and gain knowledge on how acoustical performance of existing halls is to be assessed, how relevant acoustic performance indicators of a room are extracted and how simulations in acoustic software are a useful tool for this process. The results of this study give an overview of the acoustical performance of the case studies which will provide an insight and contribute in the field of acoustics in multi-purpose halls.

1.3 Background

1.3.1 Multi-purpose halls

The use of a multi-purpose hall, according to Holden (2016), dates back to the 1920s, with the first multi-purpose halls designed to house performing arts, sports, exhibits, conferences and political conventions. Many of the first multi-purpose halls were unsuccessful in reaching a good acoustical performance in all the functions they were supposed to represent. This inspired more research on the topic which has up to today continuously grown in relevance. Many of the cases are art venues which need renovation due to a necessity of stage extension, adjustable acoustic systems or an overall improvement of the acoustics of the hall (Holden 2016). A different type of buildings, but nonetheless also a frequent case among researchers, are sport facilities in educational buildings which are meant to be used for multiple purposes. Iyendo (2014) analyses one of this type of venues and tackles the importance of background noise control for pleasant indoor acoustics.

1.3.2 Room acoustics

Most of the acoustical parameters of a room depend on the geometry of the room, the properties of the materials used, the position of the stage and the audience, as well as the position of any other entity that may react as an absorber or reflector. One of the first definitions of achieving good architectural acoustics comes from Sabine (1922):

'In order that hearing may be good in any auditorium, it is necessary that the sound should be sufficiently loud; that the simultaneous components of a complex sound should maintain their proper relative intensities; and that the successive sounds in rapidly moving articulation, either of speech or music, should be clear and distinct, free from each other and from extraneous noises.' (Sabine 1922. p.4)

According to Sabine (1922) there are three fields within which the architectural acoustics is defined:

1. Loudness

2. Distortion of Complex Sounds – Interference and Resonance

3. Confusion: Reverberation, Echo and Extraneous Sounds

Barron (2006), in his research on the development of concert hall design re-defines these fields in five points, presenting them as subjective qualities which have objective measures. (Table 1)

Table 1 The main subjective qualities in concert halls and their possible objective correlates, according to Barron (2006) (adapted from source: Barron 2006. p.6)

Subjective quality	Objective measure
Clarity	Clarity Index (C_{80})
Reverberance	Early Decay Time (EDT)
Intimacy	Sound Strength (Level)
Source broadening	Early lateral fraction and strength
Loudness	Sound strength and source-receiver distance

It is impossible to pick one parameter that will immediately define and/or describe the overall acoustic performance of a room. A room can show a correct performance in one of the qualities, and quite the opposite in another quality.

'Excellent acoustics come from the correct balance of many factors that are both interrelated and interdependent. [...] It's a domino effect---change one small thing, and there are ripples that affect everything else.' (Holden 2016. p.21)

However, a set of parameters can be chosen as ones that affect the most the performance of a room.

1.3.3 Reverberation Time

Reverberation Time is considered to be the parameter which gives the most insight on the acoustical performance of the room. It describes the amount of time that it takes for a sound to decay by 60 dB once the sound source is abruptly turned off (Sabine 1915). It is a quantity which is related to the volume of the room and the equivalent absorption area inside the volume:

$$\boldsymbol{RT = 0.16\frac{V}{A}[s]} \tag{1}$$

where RT – the reverberation time

V – the volume of the room in m^3

A – the total absorption area of the room in m^2 *(the area multiplied by the frequency-dependent absorption coefficient α)*

Ginn (1978) points out that Sabine's formula is a good indication of the RT for fairly reverberant rooms, but if the reverberance of the room decreases, respectively if absorption coefficients increase towards a maximum of 1 then the RT becomes lower and lower and should obviously eventually be 0 (as is the case in an anechoic room), which Sabine's formula does not allow because it gives a finite value of 0.16 V/A. For cases such as this one there are variations of the Sabine formula which are more adequate to be used. One of them is the Eyring formula (Ginn 1978):

$$\boldsymbol{RT} = \mathbf{0.16}\frac{\boldsymbol{V}}{-\boldsymbol{S}\,\mathbf{ln}\,(\mathbf{1}-\bar{\boldsymbol{\alpha}})}[\boldsymbol{s}] \qquad (2)$$

where RT – the reverberation time

$\bar{\alpha} = \frac{\alpha 1 s1+\alpha 2 s2+\alpha 3 s3+\cdots+\alpha n sn}{s1+s2+s3+\cdots+sn}$ – mean absorption coefficient of the room

$s=s_1+s_2+s_3+\ldots s_n$ – the areas of the various materials

$\alpha 1.\,\alpha_{2\ldots}, \alpha_n$ – the respective absorption coefficients of the materials

In cases closer to an anechoic room (i.e for α=1) Eyring's formula gives results which are in better agreement with the measured RT than Sabine's formula. The drawback to this improved formula is that it is only valid for rooms which have the same α for all surfaces. (Ginn 1978)

The optimum value of RT differs depending on the purpose of an auditorium. Generally, the RT for speech and recorded music are required to be shorter as the direct sound and clarity in these cases are very important, whereas in chamber, classical music and opera the RT is required to be longer (Figure 1).

However, it is important to point out again that solely a satisfying RT does not immediately conclude excellent acoustics of a room, especially if there are existing faults such as dead points or flutter echoes in the room.

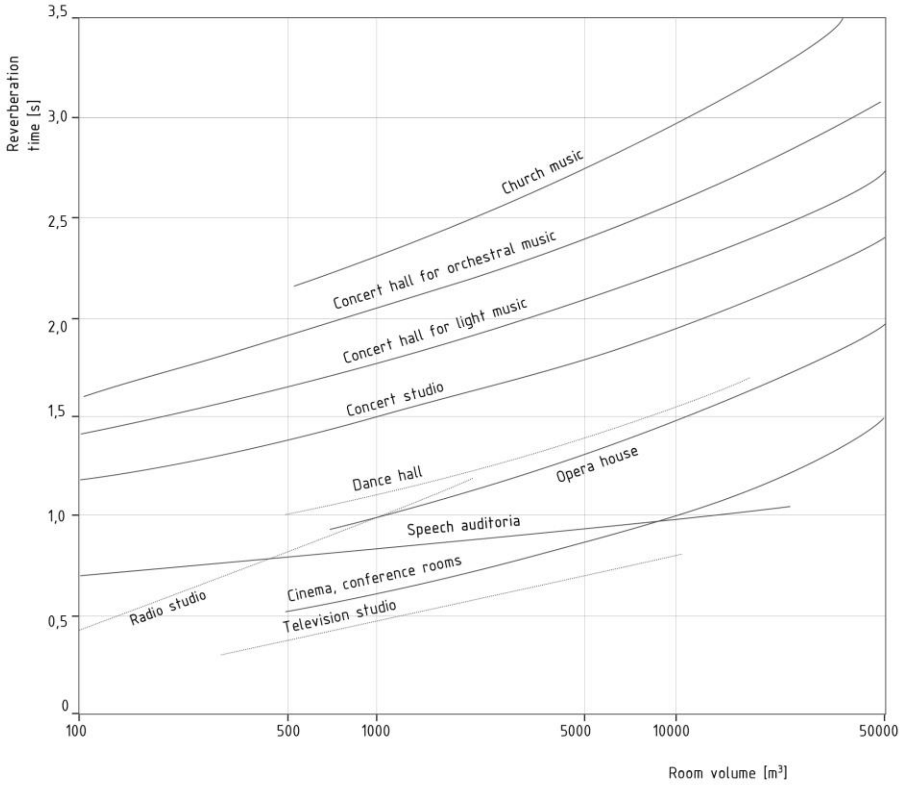

Figure 1 Purpose-dependent RT criteria (adapted from source: Ginn 1978.p.47)

1.3.4 Sound distribution

Sound distribution is perhaps the most closely related function to the geometry assessment of an auditoria. In order to achieve excellent acoustics sound needs to be distributed as uniformly as possible throughout the area occupied by the audience.

The perception of sound in a room is a function of the sound propagation from the source to the receiver as the sound energy travels through the pressure difference in the air as a longitudinal wave. This in turn is dependent on the power and directivity of the sound source, the space geometry and the characteristics of the enclosing materials of the space. The sound is therefore received in three components: direct sound, early reflections and late reflections. (Figure 2)

The direct sound is a result of a direct path between the source and the receiver without an interruption of the sound propagation (Figure 2–(A)), early reflections are the first reflections of the sound that develop in the first 80-100 ms, and the late reflections or reverberations are the reflections that occur above 2s and are considered as part of the diffuse sound field. Both early and late reflections are important features of sound propagation. Early reflections are combined with the direct sound and help in enhancing and clarifying the definition of the sound (Figure

2-(B)). They are closely related to another property of acoustic performance-C_{80} (Clarity), which is enhanced by having early reflections within 80 ms of the direct sound. Holden (2016) also states that good C_{80} is achieved from early reflections from surfaces that are specular, not diffusive. This, on the other hand, does not mean that diffuse reflections are undesirable. Diffuse reflections help with the richness of the sound and the envelopment and spaciousness of the hall.

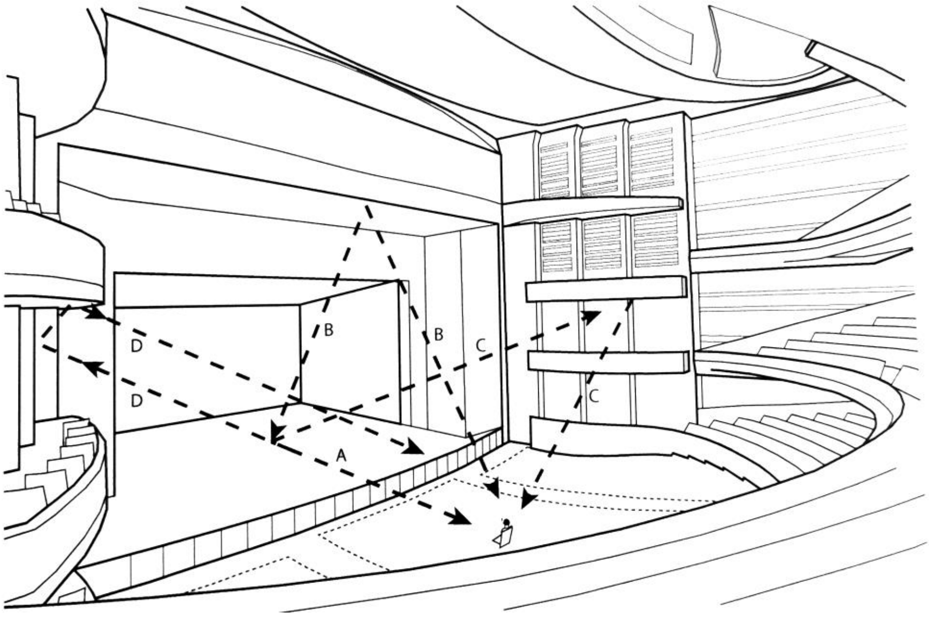

*Figure 2 Reflections at Dell Hall, Austin,TX, 2008. (**A**) Direct sound from the musician to the listener. (**B**) Ceiling reflection at 15-20 ms after direct aids clarity. (**C**) Preferred sidewall reflections 40-80 ms after direct aids clarity and spaciousness. (**D**) Soffit reflections driving early reflections down into the audience. (adapted from source: Holden 2016. p.25)*

1.3.5 Virtual acoustics and Ray-trace methods

Virtual acoustics is a useful field for assessing acoustic performance of indoor spaces. There are different types of calculation methods used in virtual acoustics: wave-based methods, ray-based methods and statistical methods (Savioja 1999). ODEON, which is the acoustic simulation software used in this paper uses ray-based methods, respectively Image Source Method, Early-Scattering Method, Ray-Tracing and Ray-Radiosity Method (ODEON, 2011).

From these general methods, two calculation methods are made, one for early reflections and one for late reflections.

The early reflections method is a mix of the Image source method (ISM) and Early Scattering Method (ESM) whereas the late reflections method is based on the Ray radiosity method (RRM) (Figure 3) (ODEON, 2019).

The Transition Order determines at which reflection order ODEON changes from the Image Source Method to the late Ray-Radiosity method (ODEON, 2019).

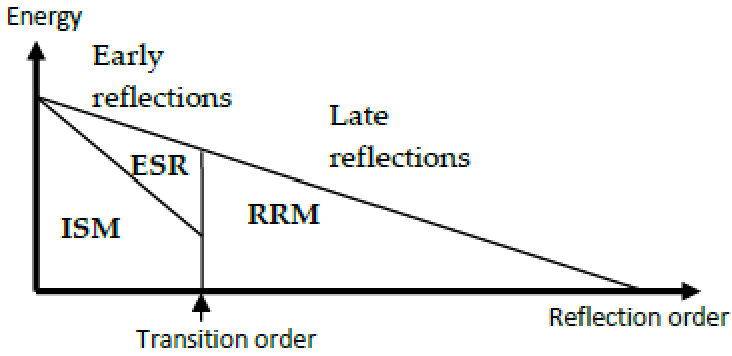

Figure 3 Early and late reflection division in ODEON (source: Odeon User's Manual 2019, p.103)

2 METHOD

2.1 Overview

The methodology of the research includes on-site measurements inside four case studies. The on-site measurements are conducted with an Omni-directional loudspeaker as the sound source and a calibrated microphone as the receiver. A grid of receivers is placed in each case study in accordance to the different size, capacity and usage of the auditorium. The multiple point results from the receivers are exported and organized in Excel and then averaged to give single values of acoustic parameters for each case study in octave-band frequencies.

Following the on-site measurements, 3D models of the case studies are generated with the help of the plan documentation provided by official representatives of the institutions of the case studies. The models are then exported into the acoustic software ODEON and the first material approximation is applied to the surfaces of the rooms. The sound source and the grid of receivers are placed in accordance to the positions of the on-site measurements and then simulations are run. Point results of the grid in the simulations are then averaged similarly to the on-site measurements in order to show corresponding single values for each case study in octave-band frequencies. The results of the first iteration of the simulations are then compared to the results of the on-site measurements and a second iteration after calibrated models is run.

2.2 Case studies

The four multi-purpose halls chosen as case studies, all of which located in Vienna, are: Halle E (Museumsquartier), Kasino am Schwarzenbergplatz, Kuppelsaal (TU Wien) and the Rote Bar (Volkstheater).

2.2.1 Halle E

Halle E is part of the Halle E+G event space located in the MuseumsQuartier complex. It was built between 1850 and 1854 as a Winter Riding Hall in the former imperial stable complex designed by architect Johann Bernhard Fischer von Erlach (MQW, 2020). Between 1985 and 1997 it became a major venue for the ‘Vienna Festwochen’ – the annual cultural festival housing numerous musical and other art performances (MQW, 2020).

Today Halle E stages cultural festivals (Vienna Festwochen, ImpulsTanz), musical performances, musical theaters, as well as social events, conferences and presentations. It is characteristic in appearance for the contrast created by the big white plaster walls and heavy drapery, against the black, heavily upholstered seating area, as well as the dark wooden floor (Figure 4).

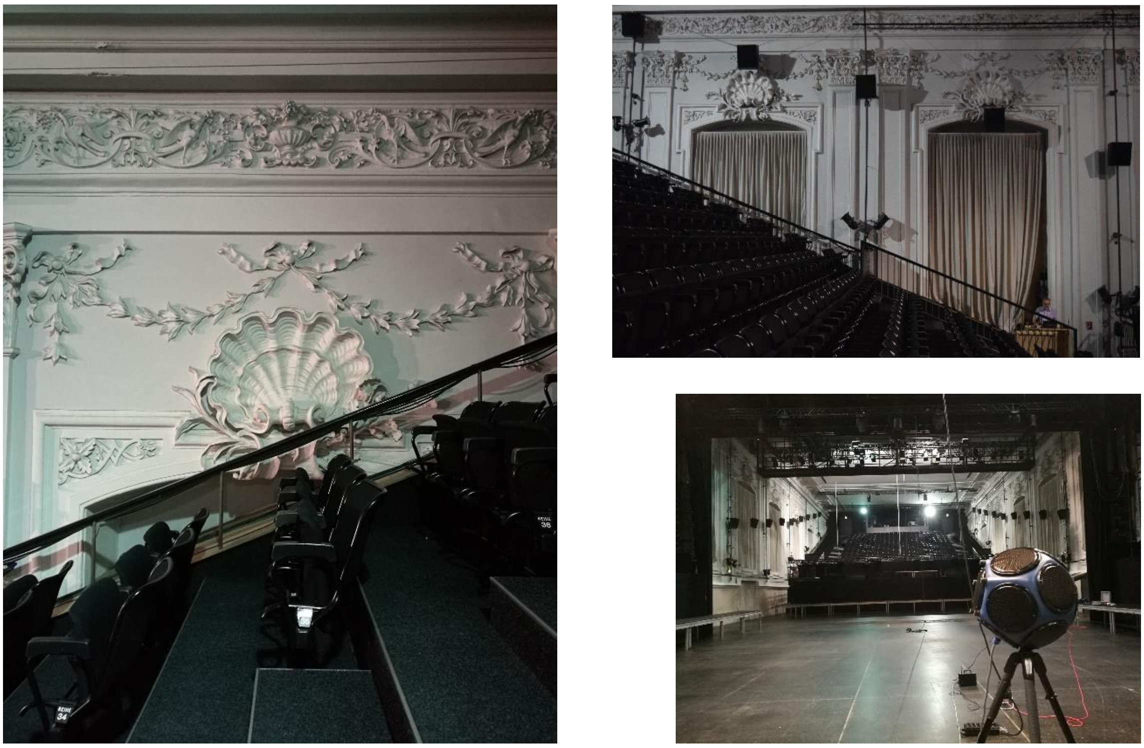

Figure 4 Halle E (photographs by author)

With a stage area of 850 m^2 and a total volume of 17 000 m^3 it has a maximum capacity of 872 seats. The first 17 seating rows can be retracted or extended (Figure 5). During the measurements they are retracted, as this is the usual state of the hall unless demanded otherwise for a specific event. There is no static stage inside the hall, therefore the measurements are set with two different positions of the speaker relative to the receivers. There were 15 receiver positions set in the auditorium during the measurements, 3 on every 4th row of the upper, un-retractable part of the auditorium.

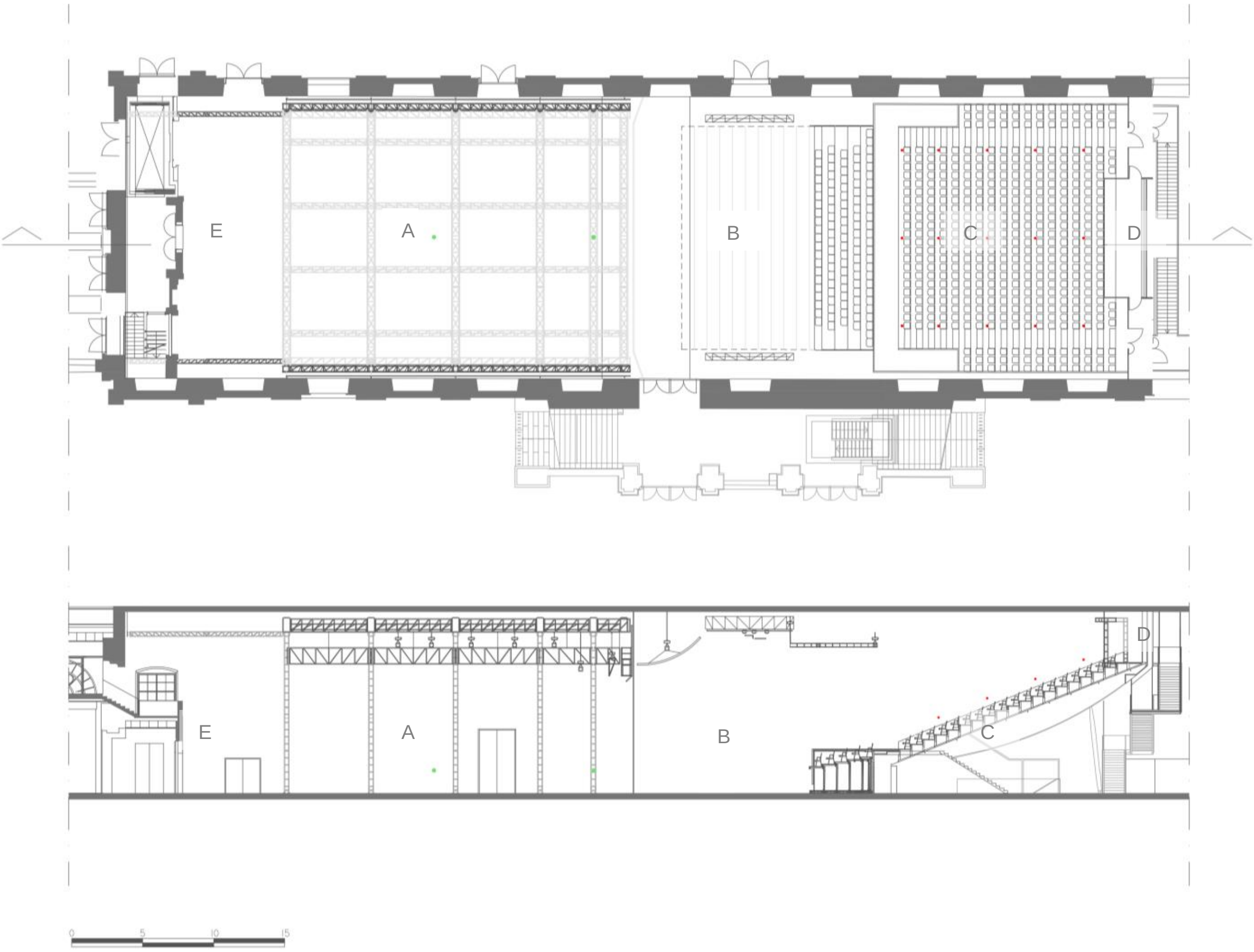

*Figure 5 Plan and section of Halle E. (**A**) Stage area (**B**) 17 rows of retractable seating area (retracted) (**C**) Audience area with upholstered seats; seat capacity of 458 seats (**D**) Tech booth (**E**) Backstage (●) Receivers positions during the measurements (●) Speakers positions during the measurements*

2.2.2 Kasino am Schwarzenbergplatz

Kasino am Schwarzenbergplatz is part of the palace designed by architect Heinrich von Ferstel for Archduke Ludwig Viktor in 1863. The hall was in this time used for private parties (BURGTHEATER, 2019). In 1900 the building was extensively renovated and then placed at the disposal of the Militärwissenschaftlicher und Casinoverein in 1910 (GESCHICHTEWIKI, 2018). In the 1980s it started to be affiliated with the Burgtheater. Today Kasino serves as a performance venue and rehearsal stage for the Burgtheater (BURGTHEATER, 2019). It is considered a venue for contemporary plays, concerts and theater projects. The stage area was rebuilt in 2010 according to the designs of the stage designer Johannes Schütz (BURGTHEATER, 2019) (Figure 6).

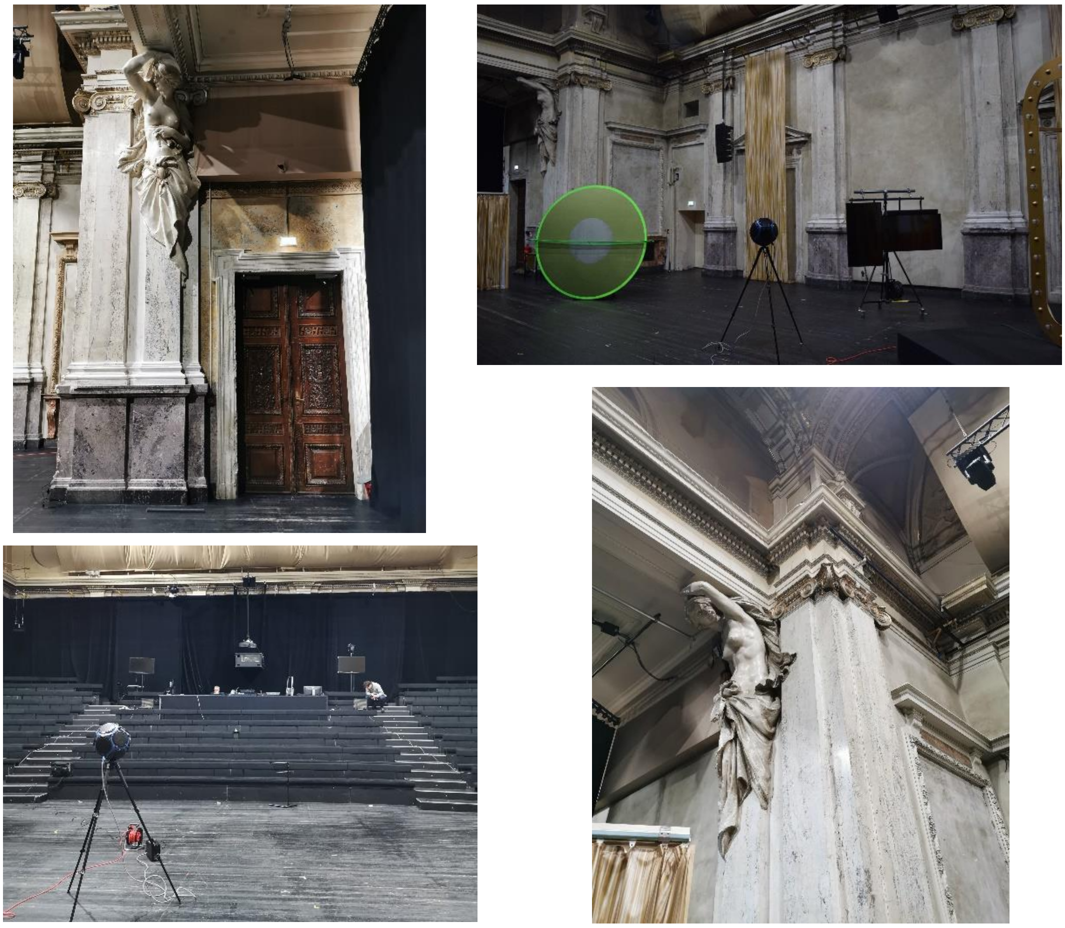

Figure 6 Kasino am Schwarzengbergplatz (photographs by author)

With a floor area of 510 m^2 and a total volume of 6000 m^3 it has a maximum capacity of 250 seats (Figure 7). The auditorium alone (without the lateral parts) has a volume of 3880 m^3. This is the way it is mostly used during performances, with the curtains closed between the auditorium and the lateral parts. The measurement involved a setting of 21 receivers positioned as shown in Figure 7.

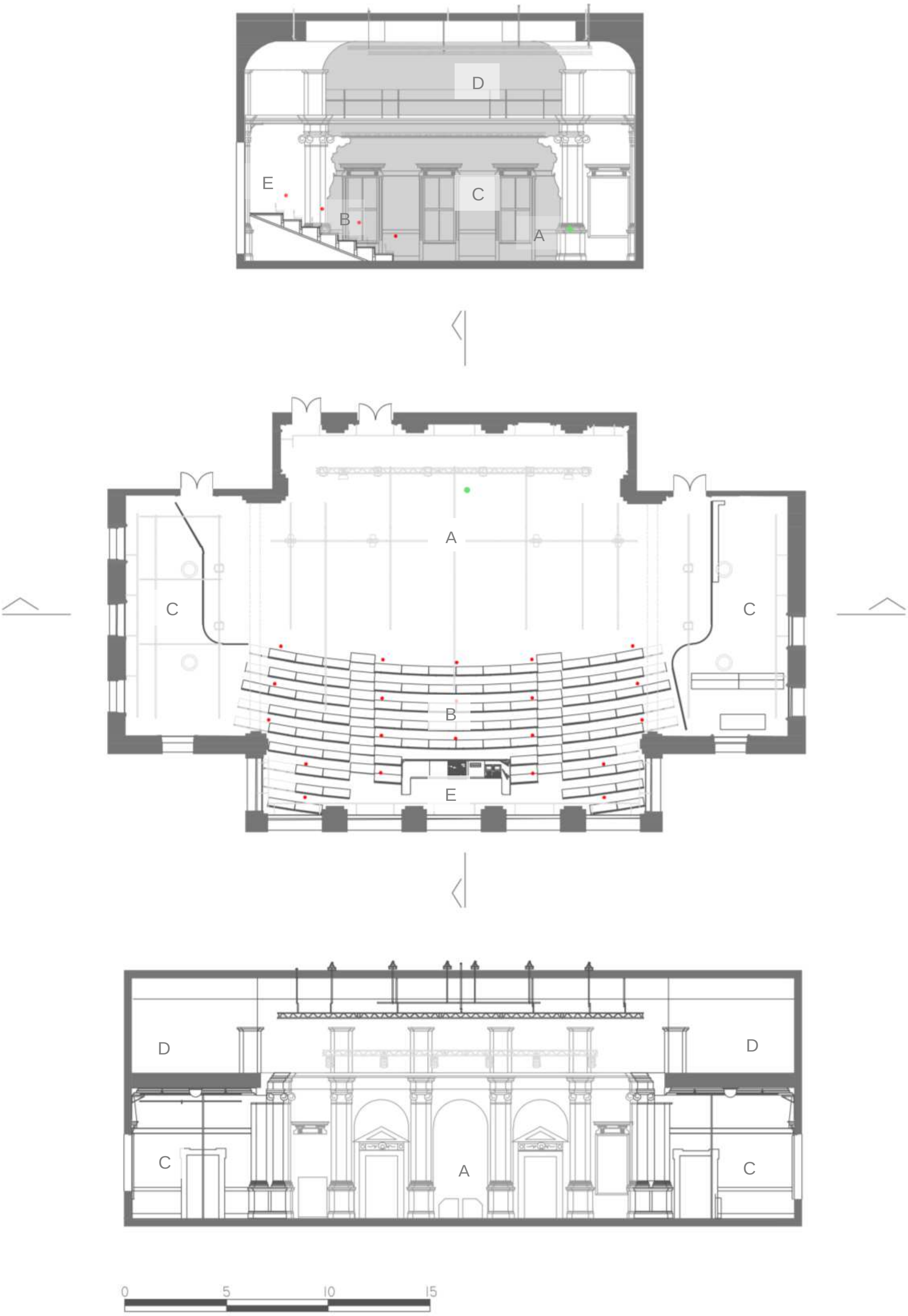

*Figure 7 Plan and Section of Kasino am Schwarzenbergplatz. (**A**) Stage area (**B**) Audience area; seat capacity of 250 seats (**C**) Lateral parts of the hall, divided from the stage area by drapes (**D**) Upper gallery, also closed with curtains (**E**) Tech booth (●) Receivers positions during the measurements (●) Speaker position during the measurements*

2.2.3 Kuppelsaal

Kuppelsaal is part of the building of the Technical University of Vienna built in 1816 and designed by architects Joseph Schemerl von Leztenbach, Joseph Stummer and Peter Nobile (GESCHICHTEWIKI, 2019). In 2007 the hall was renovated following the designs of the architecture studio NMPB (NMPB, 2007) (Figure 8). The Kuppelsaal is used as an event room where venues such as seminars, conferences, presentations, workshops and exhibitions take place (TUWIEN, 2020).

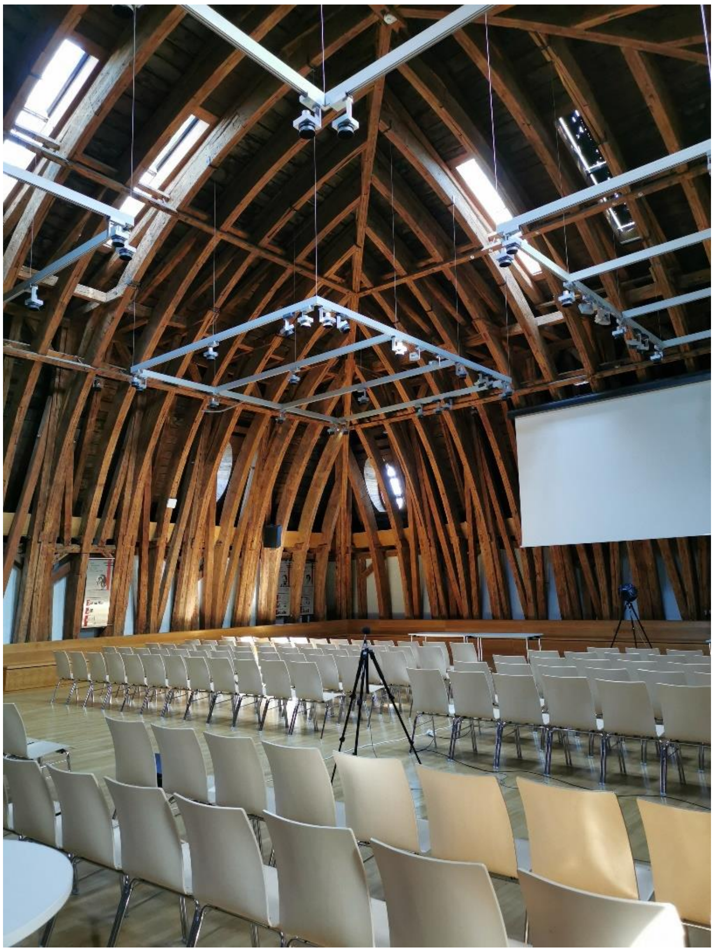

Figure 8 The Kuppelsaal (photograph by author)

With a floor area of 460 m^2 and a volume of 3420 m^3 it has a maximum capacity of 300 seats. The seats are wooden, classroom chairs and the setting of the audience depends on the venue. During the measurements the setting of the seats was 12 seats in 7 rows. The measurement involved a setting of 24 receivers distributed throughout this seat setting but also in the space behind the seats where potentially seating takes place in a different event (Figure 9).

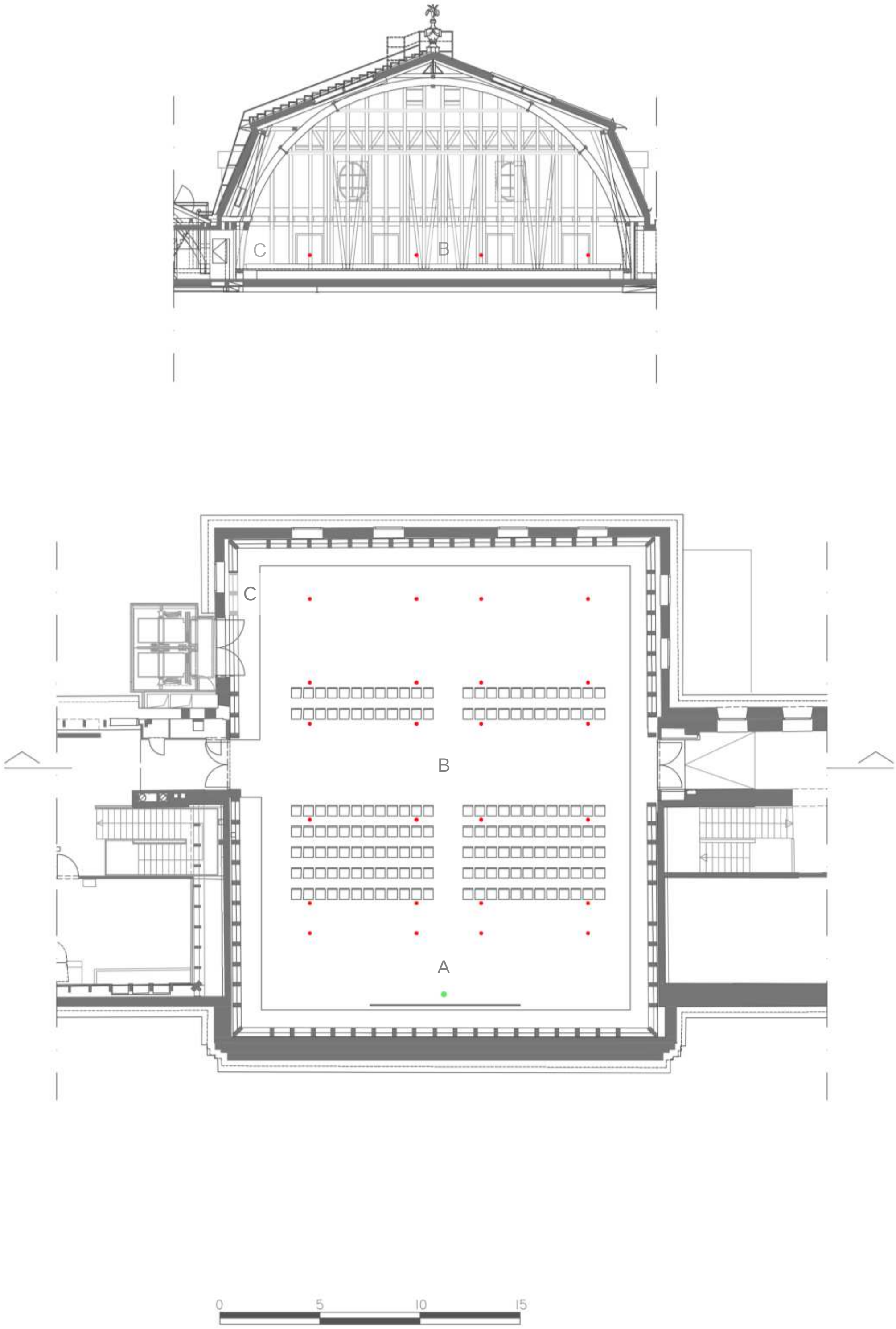

*Figure 9 Plan and Section of the Kuppelsaal. (adapted from source: NMPB Architekten) (**A**) Stage area (**B**) Audience area (**C**) Perimetral seating (●) Receivers positions during the measurements (●) Speaker position during the measurements*

2.2.4 Rote Bar

Rote Bar is part of the building of Volkstheater which was built in 1889 by architects Ferdinand Fellner and Hermann Helmer (GESCHICHTEWIKI, 2019) (Figure 10). It is a special venue which houses musical performances such as swing, soul, jazz concerts, as well as theatric performances, stand-up shows and poetry readings. Besides the stage and the audience part, it includes a bar which is in function when there are events or rehearsals happening on stage.

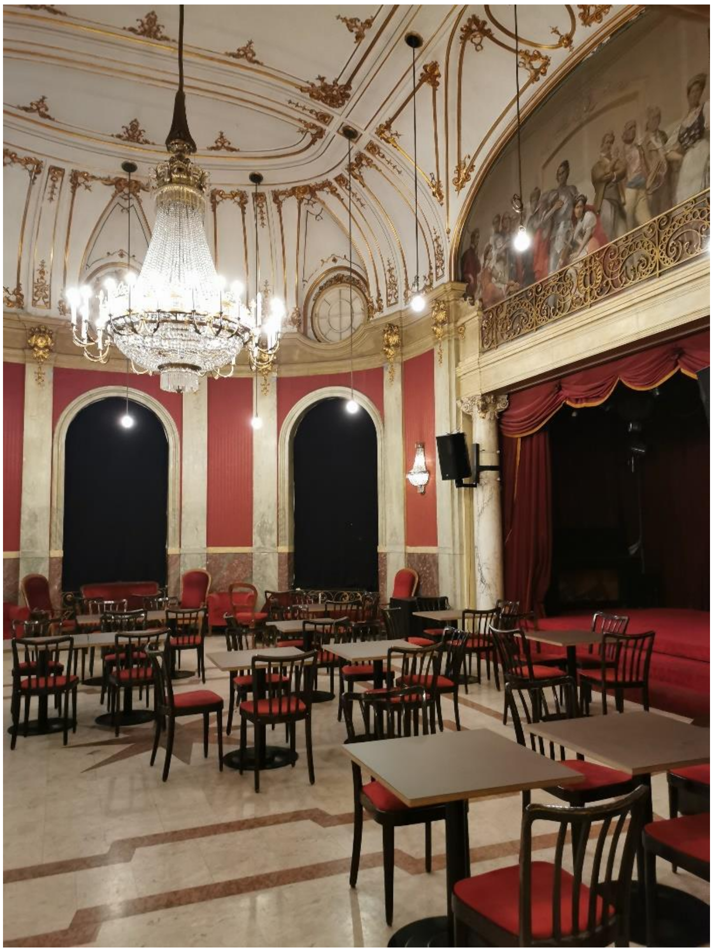

Figure 10 Rote Bar (photograph by author)

With a floor area of 110m^2 (entrance hall and stage excluded) and a volume of 1225 m^3. it has a maximum capacity of 60 seats. The measurements are performed with 14 receivers, 12 of which are positioned in the seating area and 2 by the bar (Figure 11).

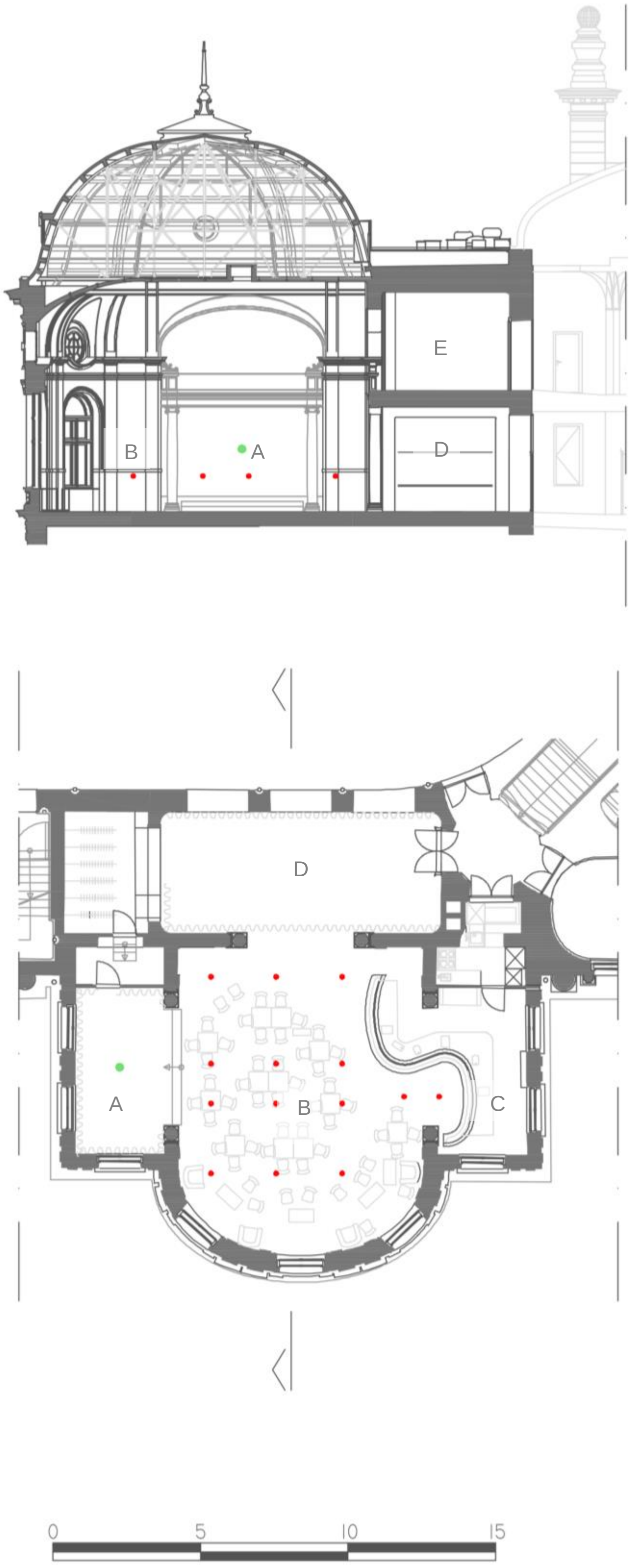

*Figure 11 Plan and Section of Rote Bar. (**A**) Stage area (**B**) Audience area; seat capacity of 60 seats (**C**) Bar and kitchen (**D**) Entrance hall (**E**) Gallery and hall (not part of the assessment) (●) Receivers positions during the measurements (●) Speaker position during the measurements*

3 RESULTS

3.1 Measurement results

3.1.1 Halle E

- **Reverberation time**

The measurement results of the RT in Halle E show higher values in the lower frequencies with up to 2.4s at 63 Hz. The RT in mid-frequencies varies from 1.86s to 1.67s between frequencies 250-2000 Hz, and then drops down in higher frequencies, with a RT of 1.07s at 8000 Hz as seen in Table 2 and Figure 12.

Table 2 Measured mean RT values by frequency band in unoccupied Halle E

Halle E	RT by frequency band [s]							
	63 **Hz**	125 **Hz**	250 **Hz**	500 **Hz**	1000 **Hz**	2000 **Hz**	4000 **Hz**	8000 **Hz**
Measured	2.45	1.87	1.86	1.96	1.86	1.67	1.33	1.07

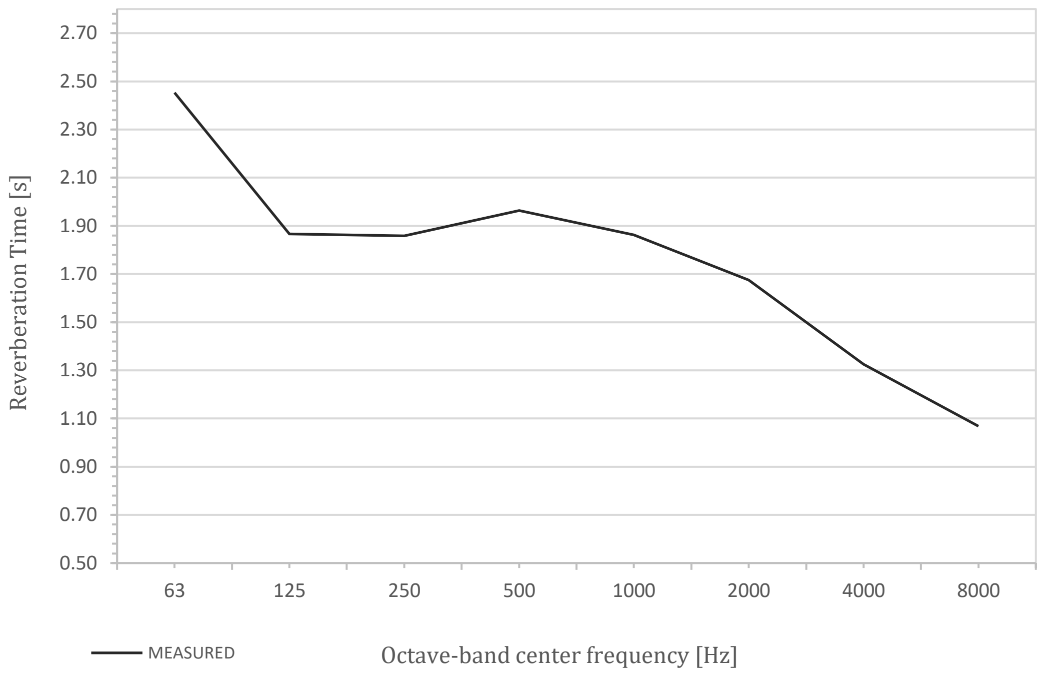

Figure 12 Measured RT in unoccupied Halle E

- **Sound distribution**

The next graphs show the measured SPL(A) from ten receivers with Speaker 1 and twelve receivers with Speaker 2 and their respective distance to the sound source (i.e. Speaker 1 in Figure 13 and Speaker 2 in Figure 14) starting from the smallest to the largest distance to the sound source.

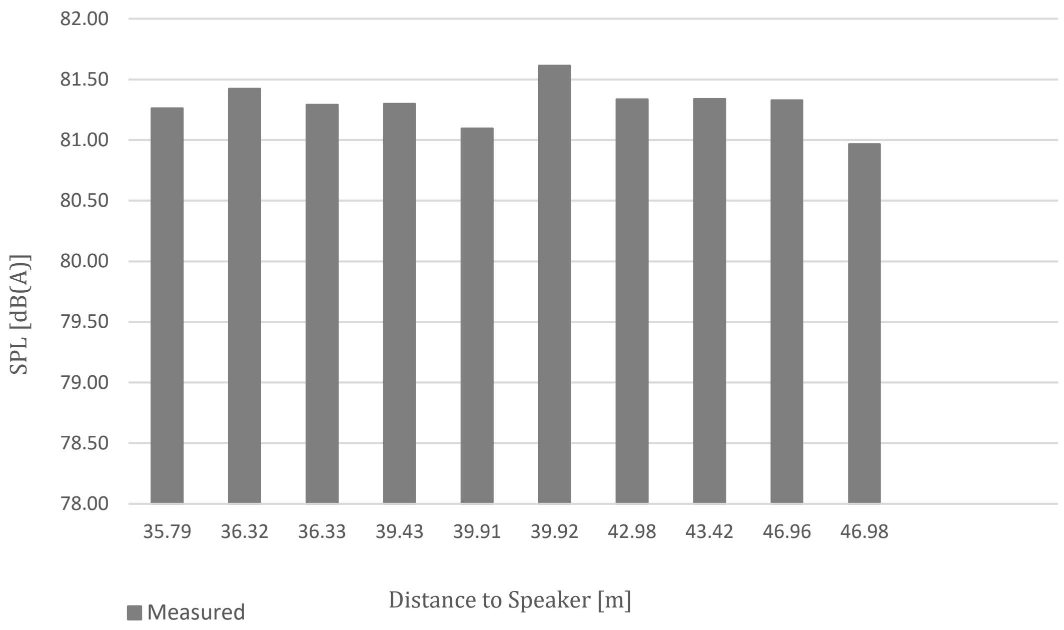

Figure 13 Measured SPL(A) in Halle E – Speaker 1

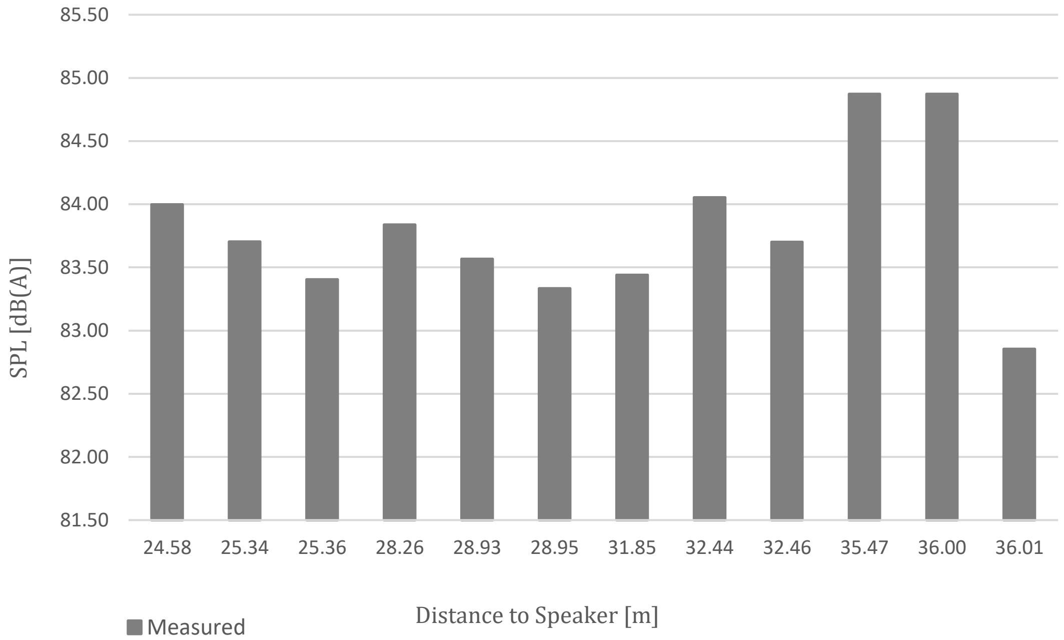

Figure 14 Measured SPL(A) in Halle E - Speaker 2

The following graphs present the measured SPL(A) drop as a function of distance; from the smallest to the largest distance to the sound source (i.e. Speaker 1 in Figure 15 and Speaker 2 in Figure 16).

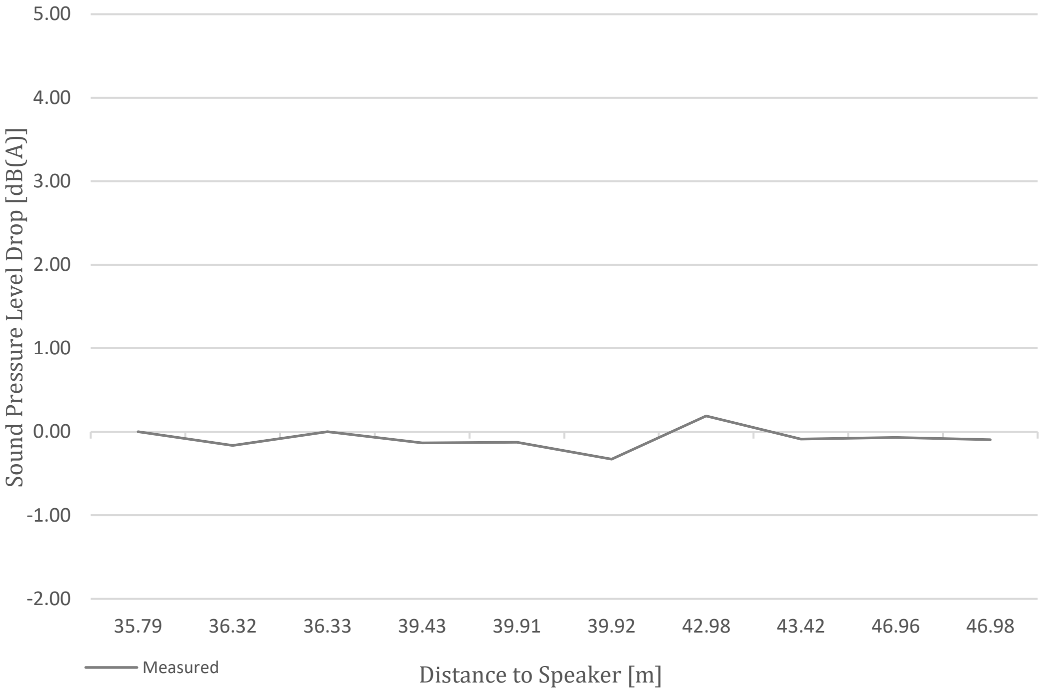

Figure 15 Measured SPL(A) drop over distance to speaker in Halle E - Speaker 1

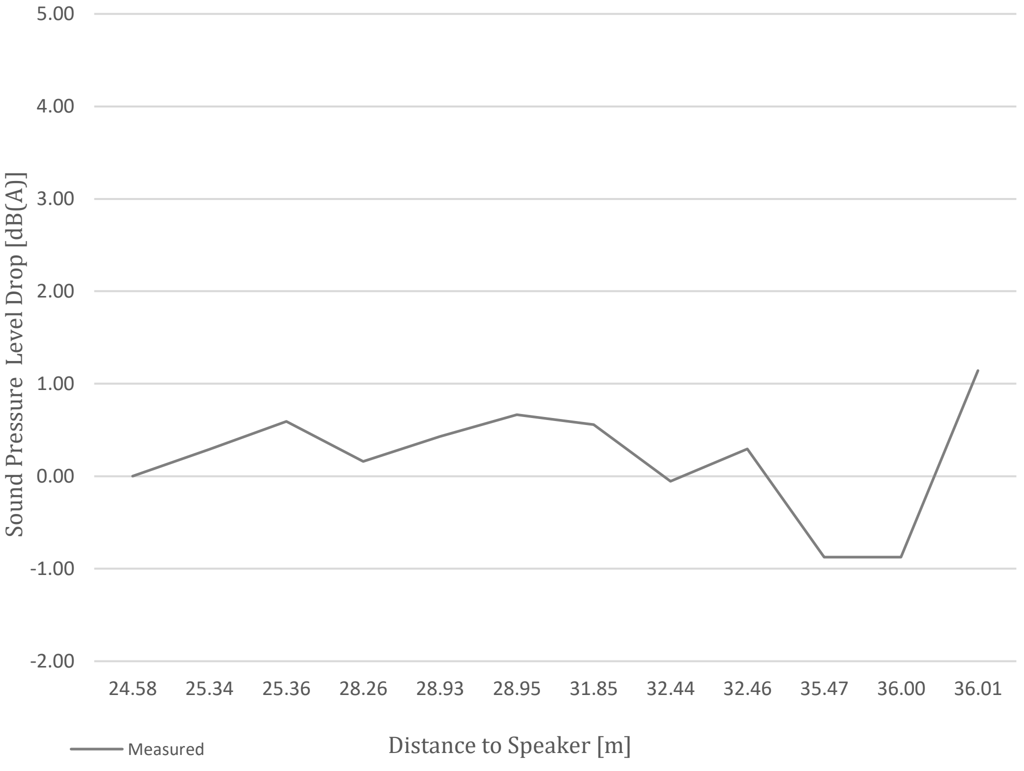

Figure 16 Measured SPL(A) drop over distance to speaker in Halle E - Speaker 2

The following table presents the distance of each of the receivers to the speakers (Table 3) and Figure 17 presents their position in the auditorium.

Table 3 Receiver distance to speaker

Receiver no.	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3
Distance to speaker1[m]	46.9	46.6	46.9	43.4	42.9	43.4	39.9	39.4	39.9	36.3	35.7	36.3
Distance to speaker2[m]	36.0	35.4	36.0	32.4	31.8	32.4	28.9	28.2	28.9	25.3	24.5	25.3

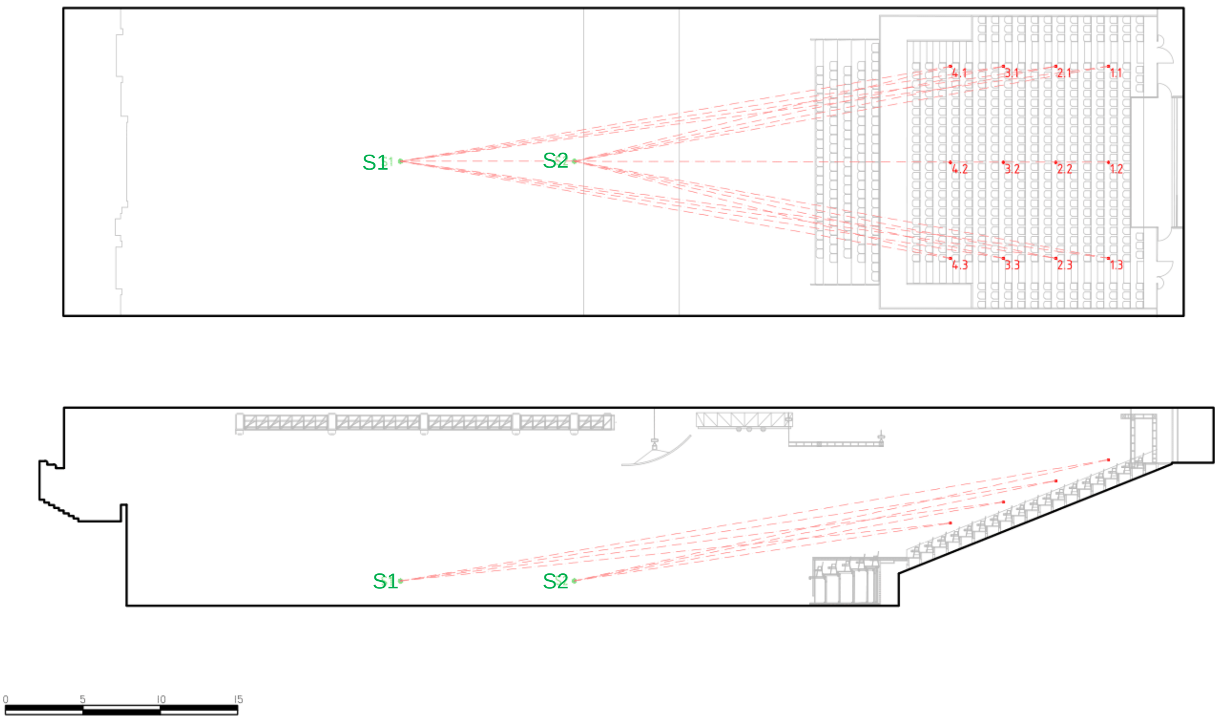

Figure 17 Receiver and speaker number and position in Halle E. (●) Receivers positions (● S1) Speaker 1 position (● S2) Speaker 2 position

3.1.2 Kasino am Schwarzenbergplatz

- **Reverberation time**

The measured RT ranges from 1.49s in the lower frequencies to 0.87s in the higher frequencies (Table 4, Figure 18).

Table 4 Measured mean RT values by frequency band in unoccupied Kasino am Schwarzenbergplatz

Kasino	RT by frequency band [s]							
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Measured	/	1.49	1.29	1.27	1.25	1.19	0.98	0.87

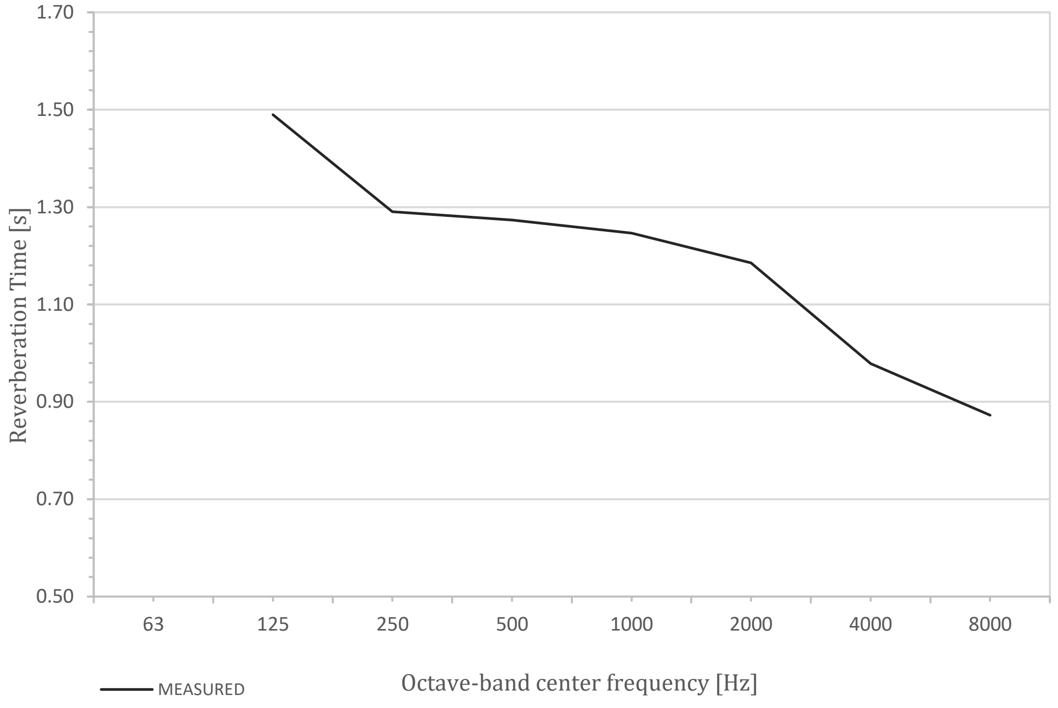

Figure 18 Measured RT in unoccupied Kasino am Schwarzenbergplatz

- **Sound distribution**

The next graphs show the measured SPL(A) from fifteen receivers and their respective distance to the sound source (Figure 19) starting from the smallest to the largest distance to the sound source.

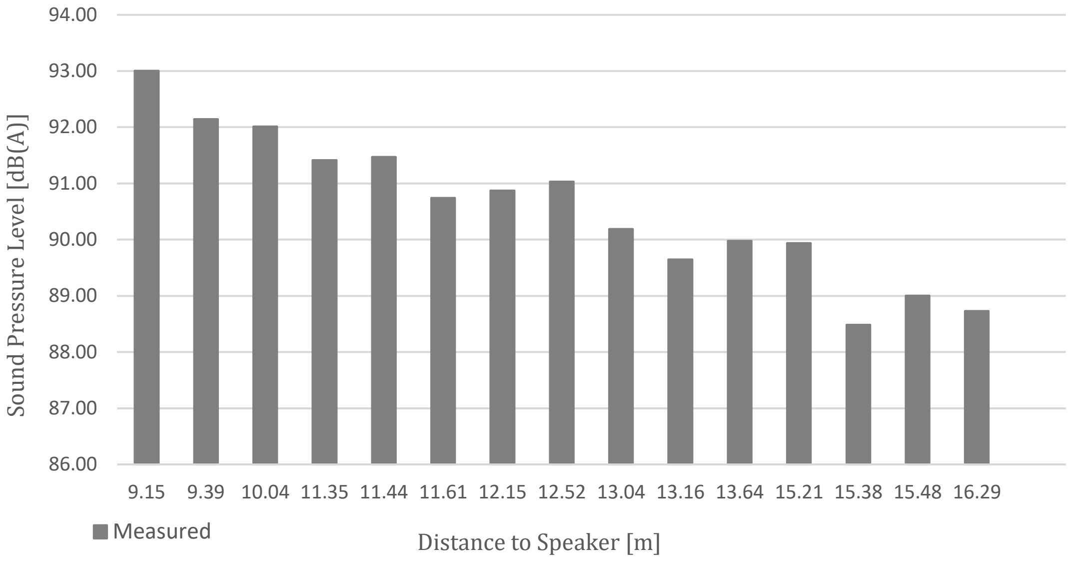

Figure 19 Measured SPL(A) in Kasino am Schwarzenbergplatz

The following graph presents the measured SPL(A) drop as a function of distance - from the smallest to the largest distance to the sound source (Figure 20).

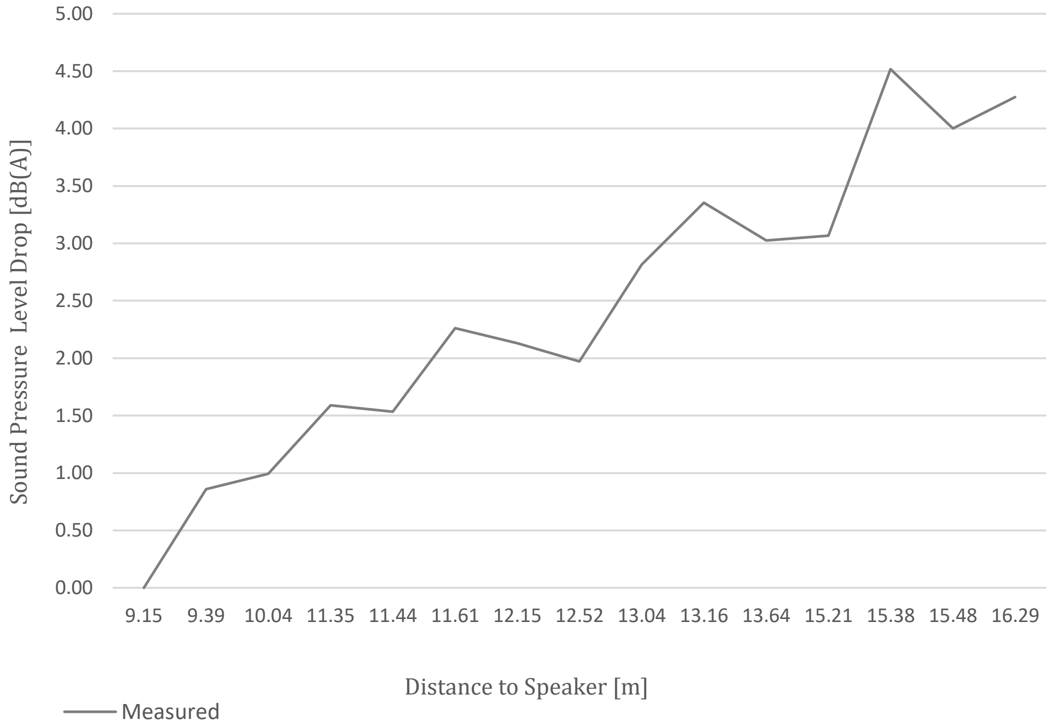

Figure 20 Measured SPL(A) drop over distance to speaker in Kasino am Schwarzenbergplatz

The following table shows the distance of the point receivers to the speaker (Table 5) and Figure 21 presents their position in the auditorium.

Table 5 Receiver distance to speaker

Receiver no.	1.1	1.2	1.3	1.4	1.5	2.2	2.3	2.4
Distance to speaker[m]	11.3	9.3	9.1	10	12.5	11.6	11.4	12.1
Receiver no.	3.1	3.2	3.3	3.4	3.5	4.1	4.3	4.4
Distance to speaker[m]	14.5	13.1	13.0	13.6	15.3	15.4	15.2	16.2

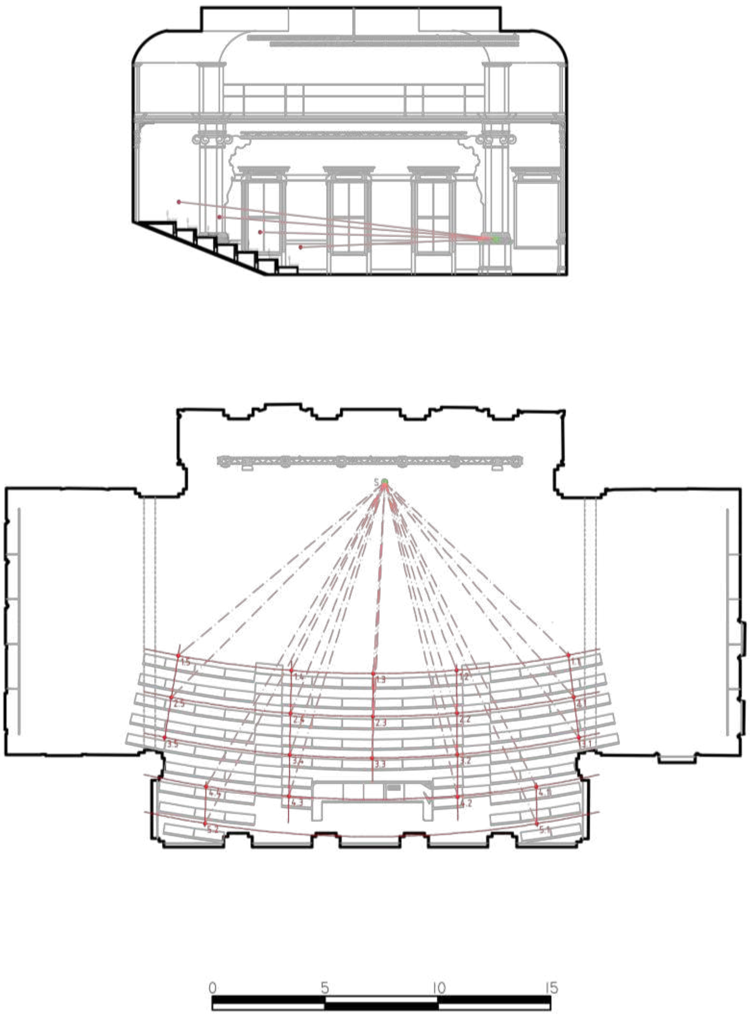

Figure 21 Receiver and speaker number and position in Kasino am Schwarzenbergplatz. (●) Receivers positions (●S) Speaker position

3.1.3 Kuppelsaal

- **Reverberation time**

The measured RT ranges from 1.43s in the lowest measured frequency to 0.69s in the highest measured frequency (Table 6, Figure 22).

Table 6 Measured mean RT by frequency band in unoccupied Kuppelsaal

Kuppelsaal	**RT by frequency band [s]**							
	63 **Hz**	125 **Hz**	250 **Hz**	500 **Hz**	1000 **Hz**	2000 **Hz**	4000 **Hz**	8000 **Hz**
Measured	1.43	1.39	1.47	1.21	1.15	1.08	0.93	0.69

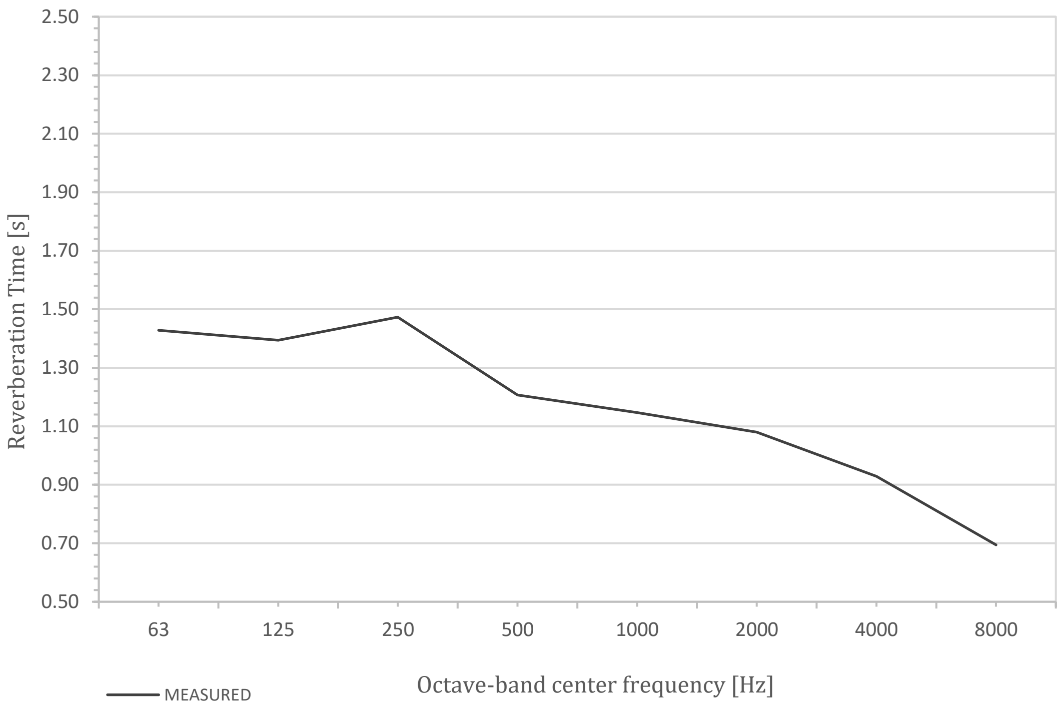

Figure 22 Measured RT in unoccupied Kuppelsaal

- **Sound distribution**

The next graph shows the measured SPL(A) from twenty one receivers and their respective distance to the sound source starting from the smallest to the largest distance to the sound source (Figure 23).

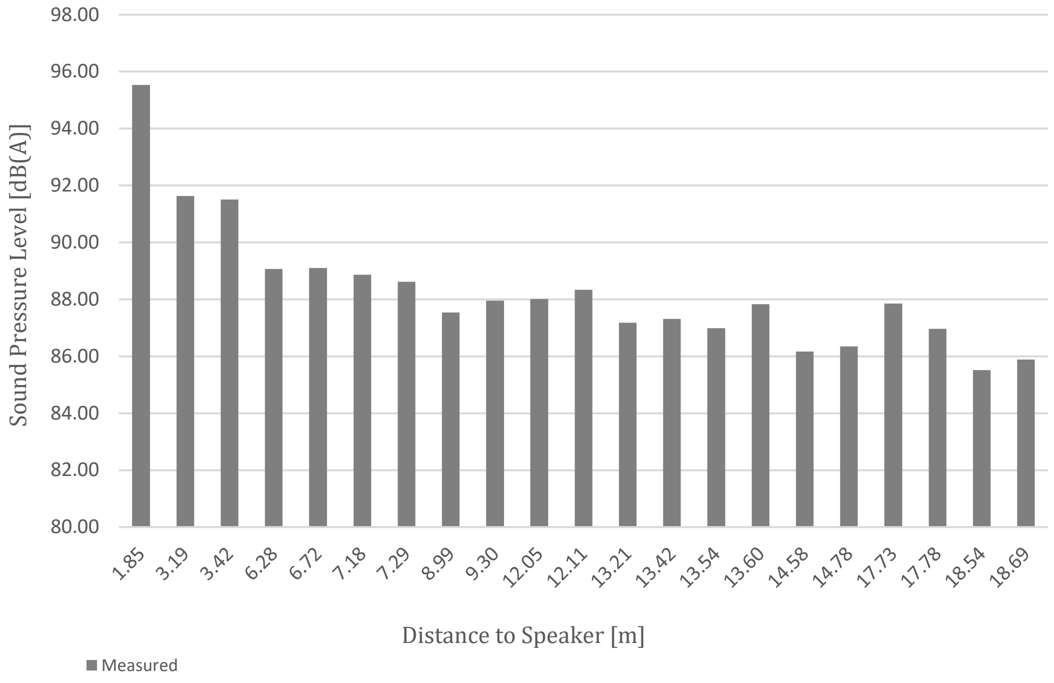

Figure 23 Measured SPL(A) in Kuppelsaal

The following graph presents the measured SPL(A) drop as a function of distance - from the smallest to the largest distance to the sound source (Figure 24).

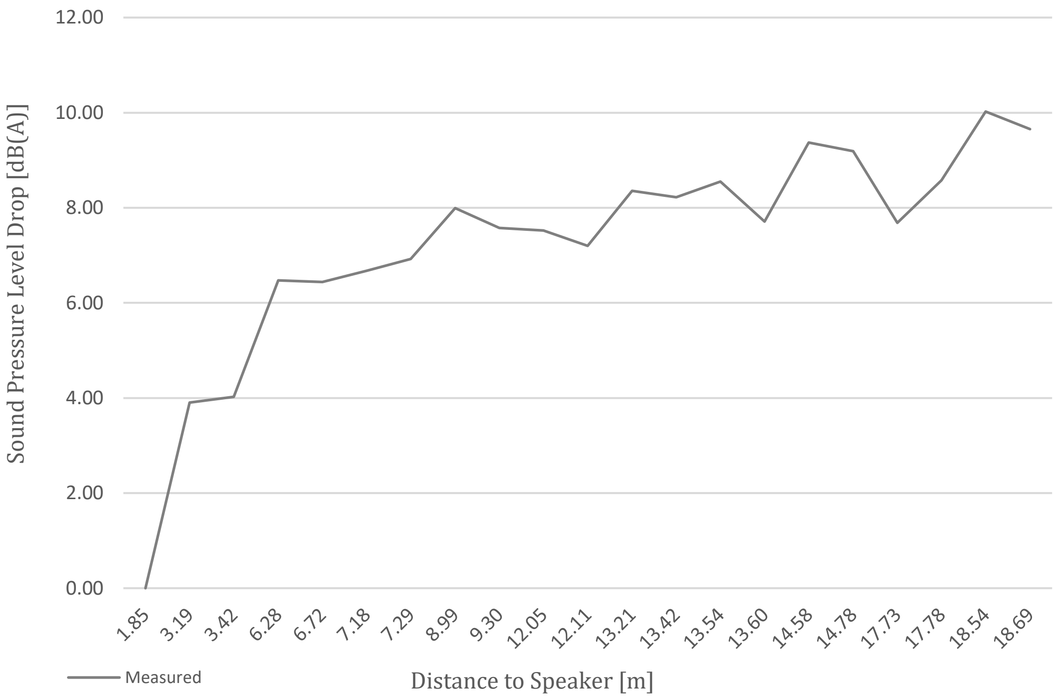

Figure 24 Measured SPL(A) drop over distance to speaker in Kuppelsaal

The following table shows the distance of the point receivers to the speaker (Table 7) and Figure 25 presents their position in the auditorium.

Table 7 Receiver distance to speaker

Receiver no.	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1	3.2
Distance to speaker[m]	6.28	3.19	3.42	6.72	8.99	7.18	7.29	9.30	13.21	12.05
Receiver no.	3.3	3.4	4.1	4.2	4.3	4.4	5.1	5.2	5.3	5.4
Distance to speaker[m]	12.11	13.42	14.58	13.54	13.60	14.78	18.54	17.73	17.78	18.69

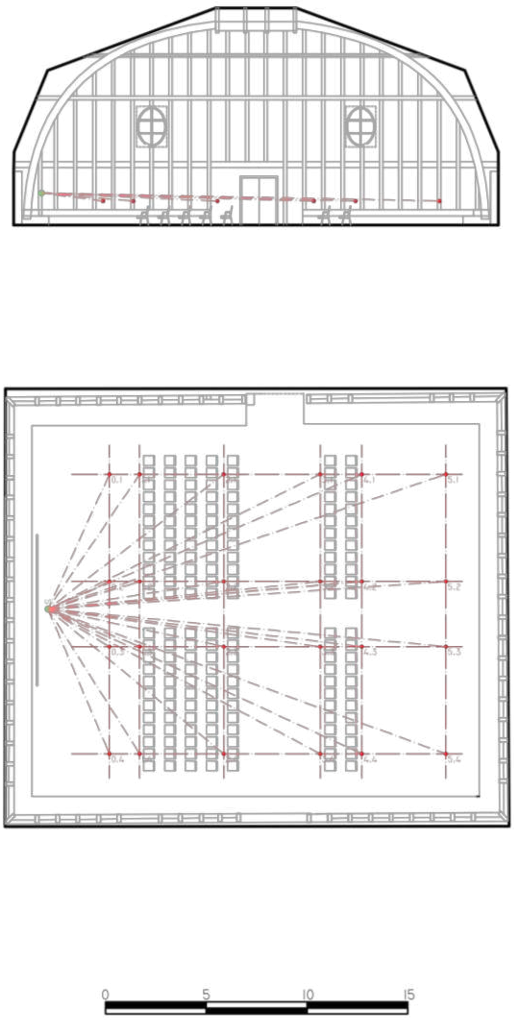

Figure 25 Receiver and speaker number and position in Kuppelsaal. (●) Receivers positions (● S) Speaker position

3.1.4 Rote Bar

- **Reverberation time**

The measured RT ranges from 2.3s in the lowest measured frequency to 0.67s in the highest measured frequency (Table 8, Figure 26).

Table 8 Measured mean RT by frequency band in Rote Bar

Rote bar	RT by frequency band [s]							
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Measured	/	2.30	1.36	1.03	0.94	0.93	0.84	0.67

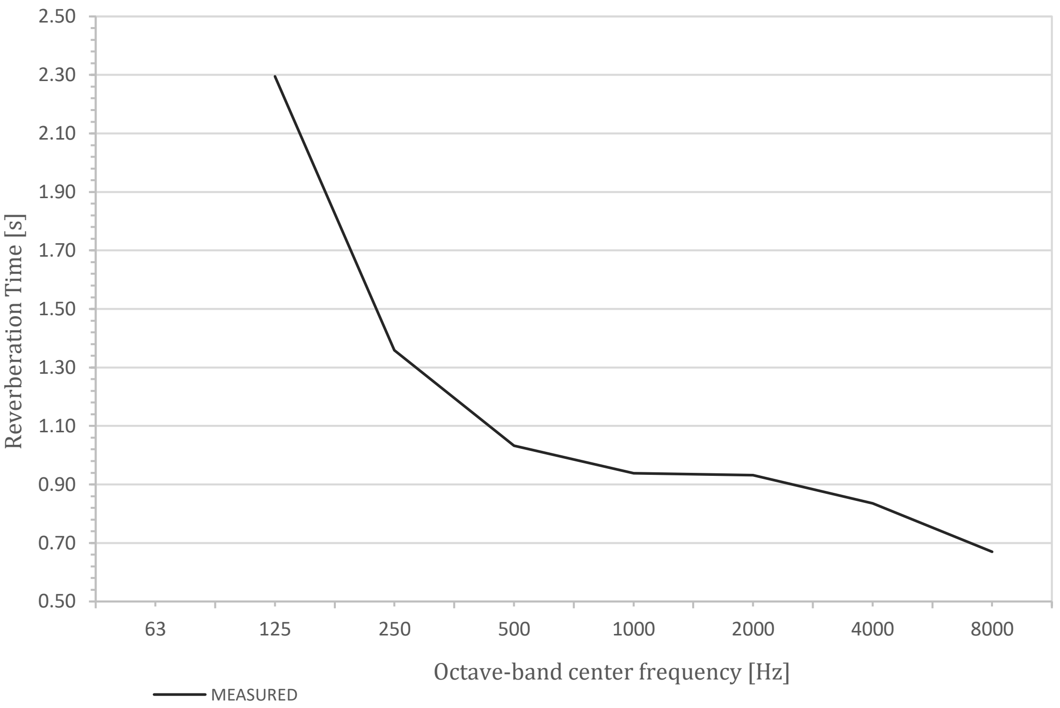

Figure 26 Measured RT in unoccupied Rote Bar

- **Sound distribution**

The next graphs show the measured SPL(A) from fourteen receivers and their respective distance to the sound source starting from the smallest to the largest distance to the sound source (Figure 27).

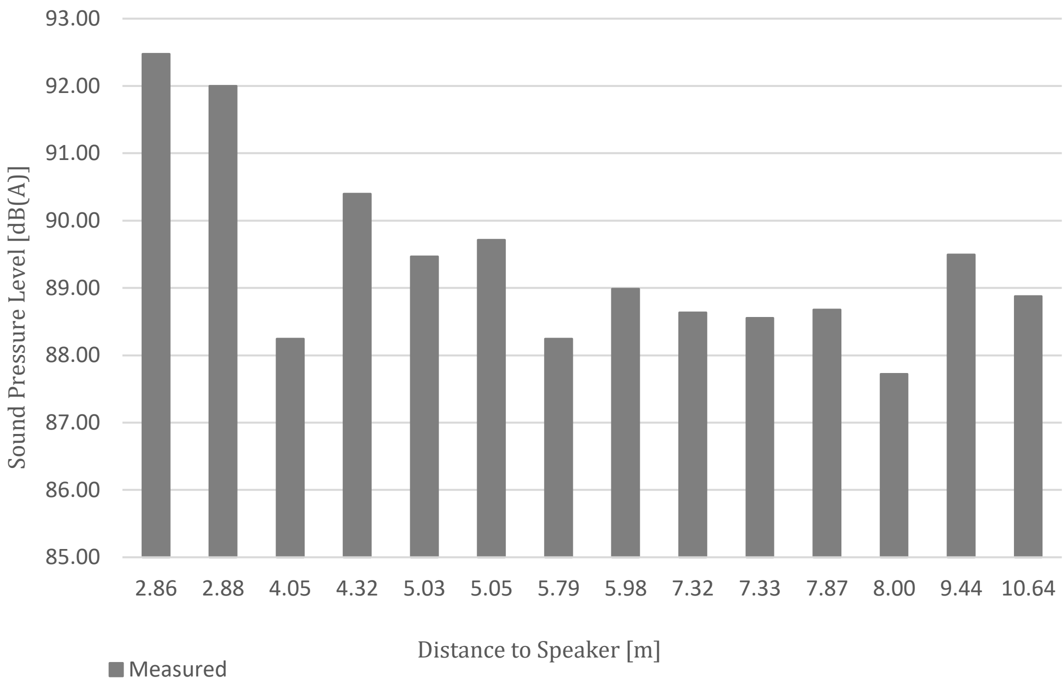

Figure 27 Measured SPL(A) in Rote Bar

The following graph presents the measured SPL(A) drop as a function of distance - from the smallest to the largest distance to the sound source (Figure 28).

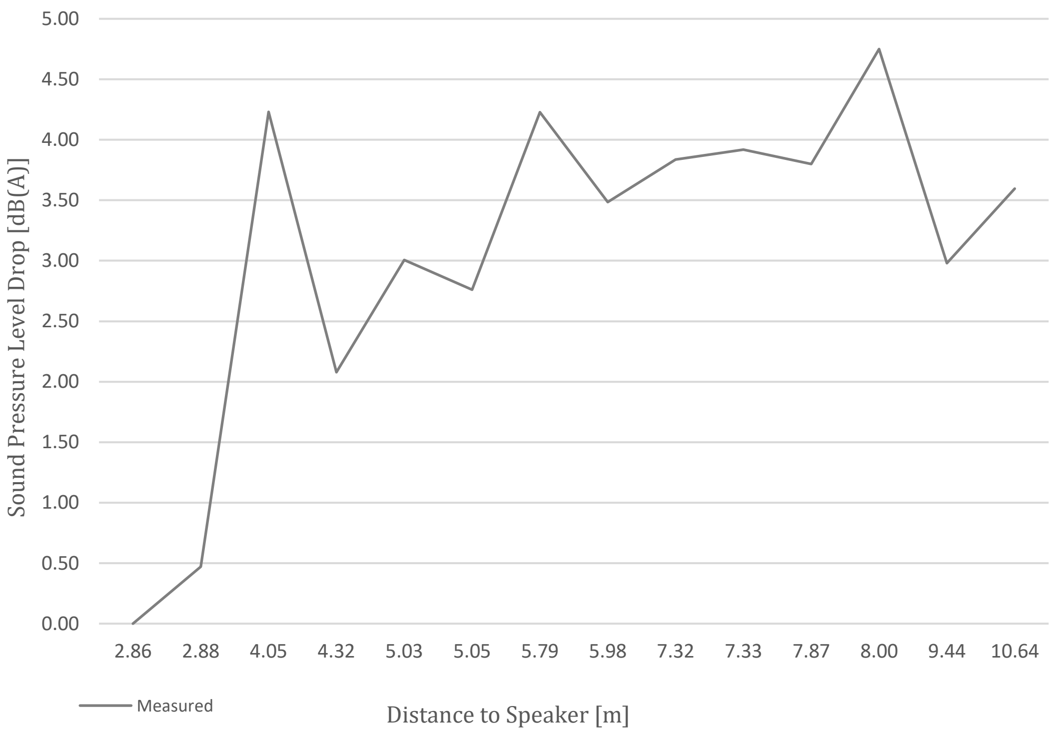

Figure 28 Measured SPL(A) drop over distance to speaker in Rote Bar

The following table shows the distance of these point receivers to the speaker (Table 9) and Figure 29 presents their position in the auditorium.

Table 9 Receiver distance to speaker

Receiver no.	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4	4.1	5.1
Distance to speaker[m]	4.3	2.9	2.86	4.1	6	5.1	5.0	5.8	8.0	7.3	7.3	7.9	9.4	10.6

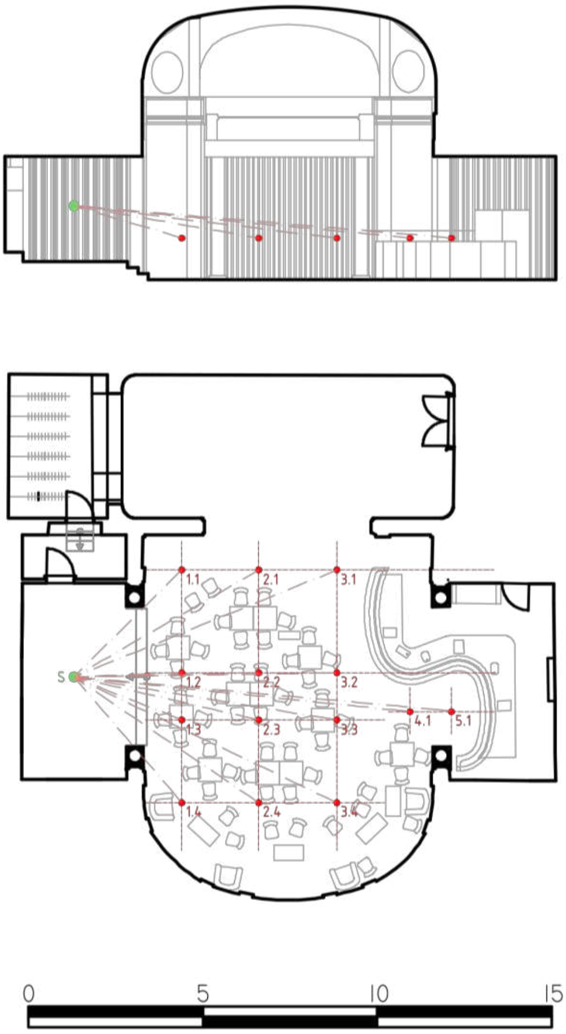

Figure 29 Receiver and speaker number and position in Rote Bar. (●) Receivers positions (●S) Speaker position

3.2 Simulation models and calibration

3.2.1 Halle E

The following table and graph present the RT values in the simulated model (Table 10, Figure 30). These RT values are the average of two iterations run with the same surface material properties and sound source power but different speaker position. The table and graph also contain the results of the measured RT previously presented in Section 3.1.1.

Table 10 Measured and simulated mean RT values by frequency band in unoccupied Halle E

Halle E	RT by frequency band [s]							
	63 **Hz**	125 **Hz**	250 **Hz**	500 **Hz**	1000 **Hz**	2000 **Hz**	4000 **Hz**	8000 **Hz**
Measured	2.45	1.87	1.86	1.96	1.86	1.67	1.33	1.07
Simulated	2.15	2.19	1.97	1.81	1.86	1.88	1.56	0.90

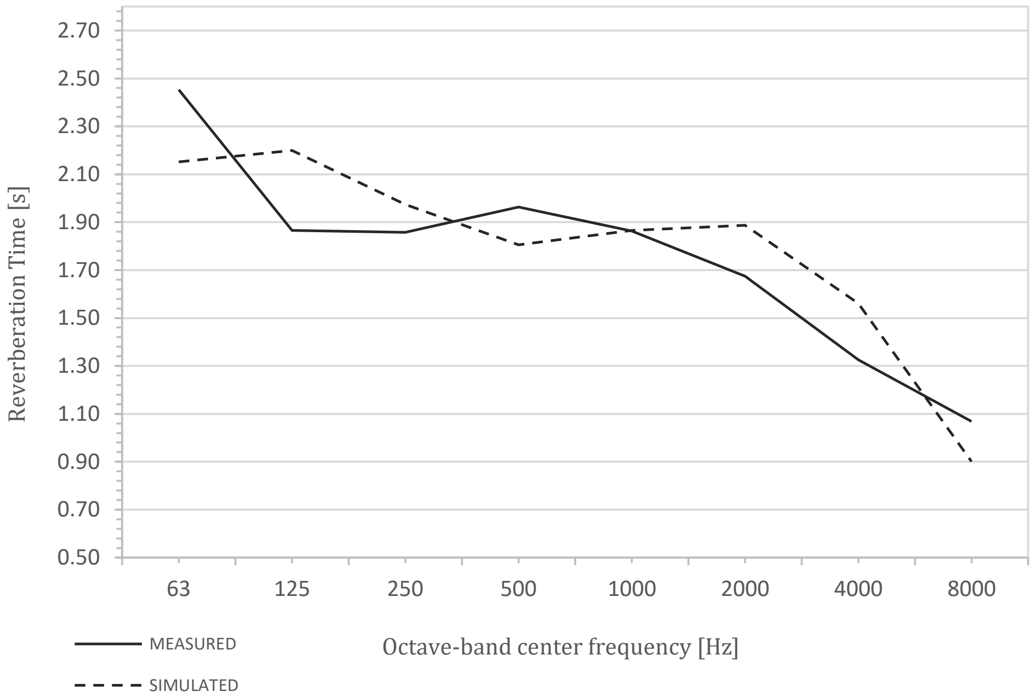

Figure 30 Simulated and measured mean RT in unoccupied Halle E

The following table lists the surfaces used to model the geometry of Halle E in Odeon. The set of materials assigned to these surfaces is presented together with the absorption coefficients in octave-band frequencies (Table 11). All materials used in the simulation model were taken from the material library that the software provides.

Table 11 Surface areas and material absorption coefficients by frequency band for the materials used in the simulation of Halle E

Surface	Area[m²]	Finish materials	Sound absorption coefficient by frequency band (α)							
			63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Walls and ceiling	3097	Painted plaster surface	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Furniture	200	Wood	0.14	0.14	0.1	0.06	0.08	0.1	0.1	0.1
	568	Canvas	0.95	0.9	0.7	0.5	0.35	0.25	0.15	0.15
	20.1	Thin plywood panelling	0.42	0.42	0.21	0.1	0.08	0.06	0.06	0.06
	38.5	Steel trapeze profile	0.4	0.3	0.25	0.2	0.1	0.1	0.15	0.15
Drapes	347	Heavy velour	0.14	0.14	0.35	0.55	0.72	0.7	0.65	0.65
	48.6	Medium velour	0.07	0.07	0.31	0.49	0.75	0.7	0.6	0.6
Floor	1150	Wooden parquet	0.04	0.04	0.04	0.07	0.06	0.06	0.07	0.07
Curtains	345.8	Densely woven	0.06	0.06	0.1	0.38	0.63	0.7	0.73	0.73
	461	Cotton curtains	0.3	0.3	0.45	0.65	0.56	0.59	0.71	0.71
Audience flooring area	118.2	Tufted pile carpet	0.08	0.08	0.08	0.3	0.6	0.75	0.8	0.8
Doors	57	Solid wooden door	0.14	0.14	0.1	0.06	0.08	0.1	0.1	0.1
Auditorium	335	Heavily upholstered chairs	0.72	0.72	0.79	0.83	0.84	0.83	0.79	0.79

The following graphs presents the results of SPL(A) in the simulated model (Figure 31 and 32), as well as the results of SPL(A) drop (Figures 33 and 34). The results of the simulations are presented next to the measured SPL(A) and SPL(A) drop values previously seen in Section 3.1.1.

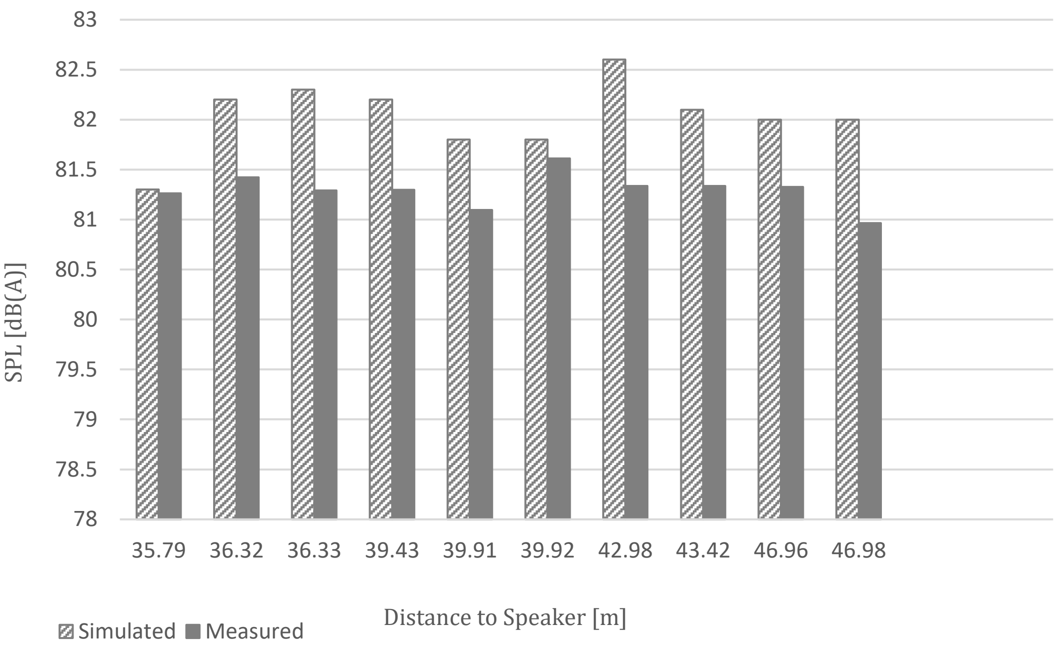

Figure 31 Simulated and measured SPL(A) in Halle E – Speaker 1

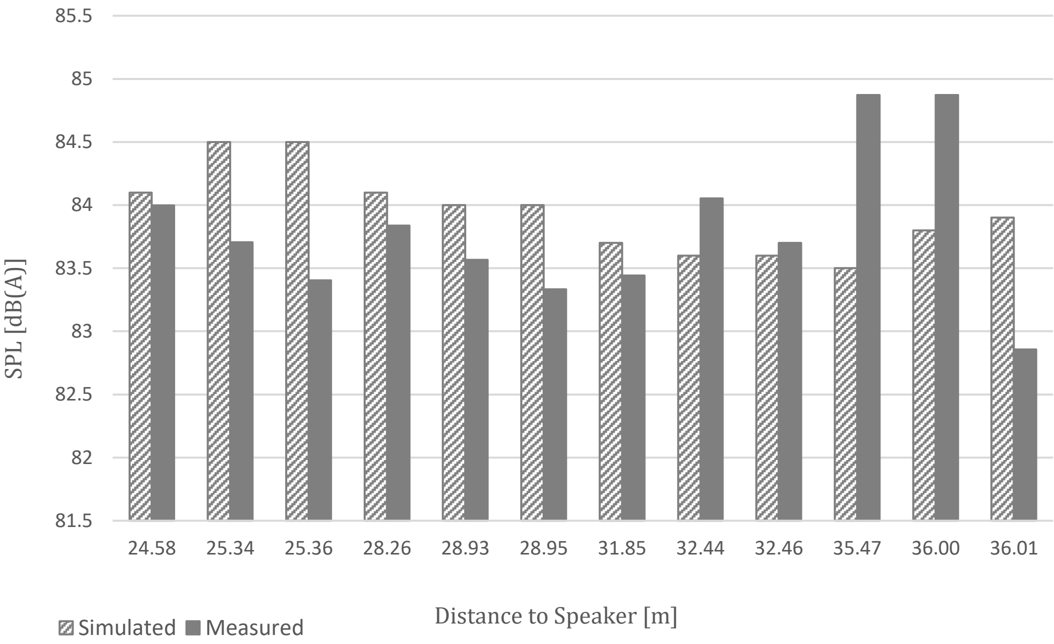

Figure 32 Simulated and measured SPL(A) in Halle E - Speaker 2

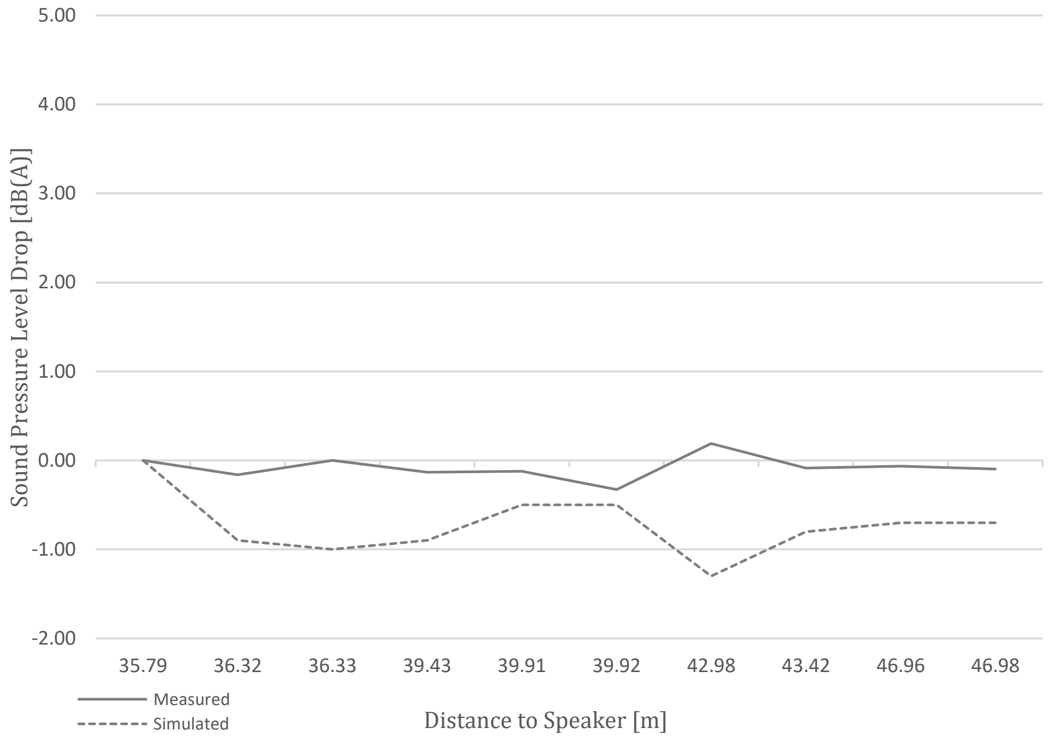

Figure 33 Simulated and measured SPL(A) drop in Halle E - Speaker 1

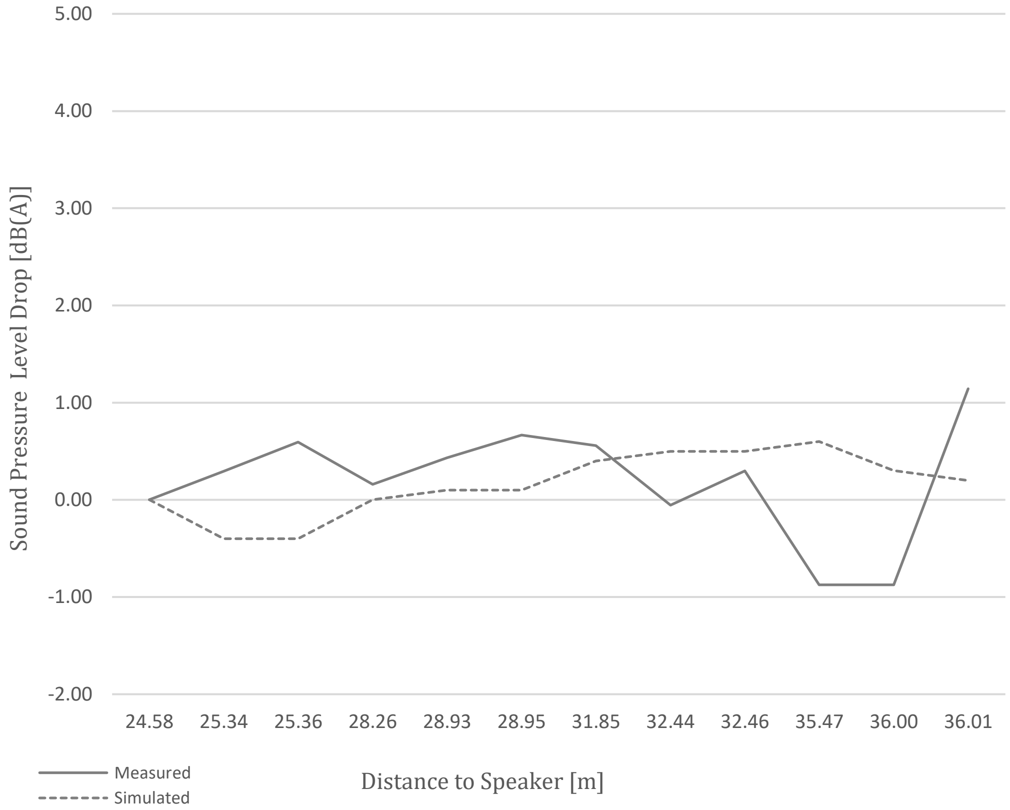

Figure 34 Simulated and measured SPL(A) drop in Halle E - Speaker 2

3.2.2 Kasino am Schwarzenbergplatz

The following table and graph present the RT values in the simulated model (Table 12, Figure 35). They contain the results of the first iteration and the second one. The table and graph also show the results of the measured RT previously shown in Section 3.1.2.

Table 12 Measured and simulated mean RT values by frequency band in unoccupied Kasino am Schwarzenbergplatz

Kasino	RT by frequency band [s]							
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Measured	/	1.49	1.29	1.27	1.25	1.19	0.98	0.87
Simulated (Iteration I)	3.13	3.26	2.01	1.72	1.53	1.47	1.26	0.77
Simulated (Iteration II)	1.57	1.65	1.40	1.46	1.39	1.44	1.30	0.79

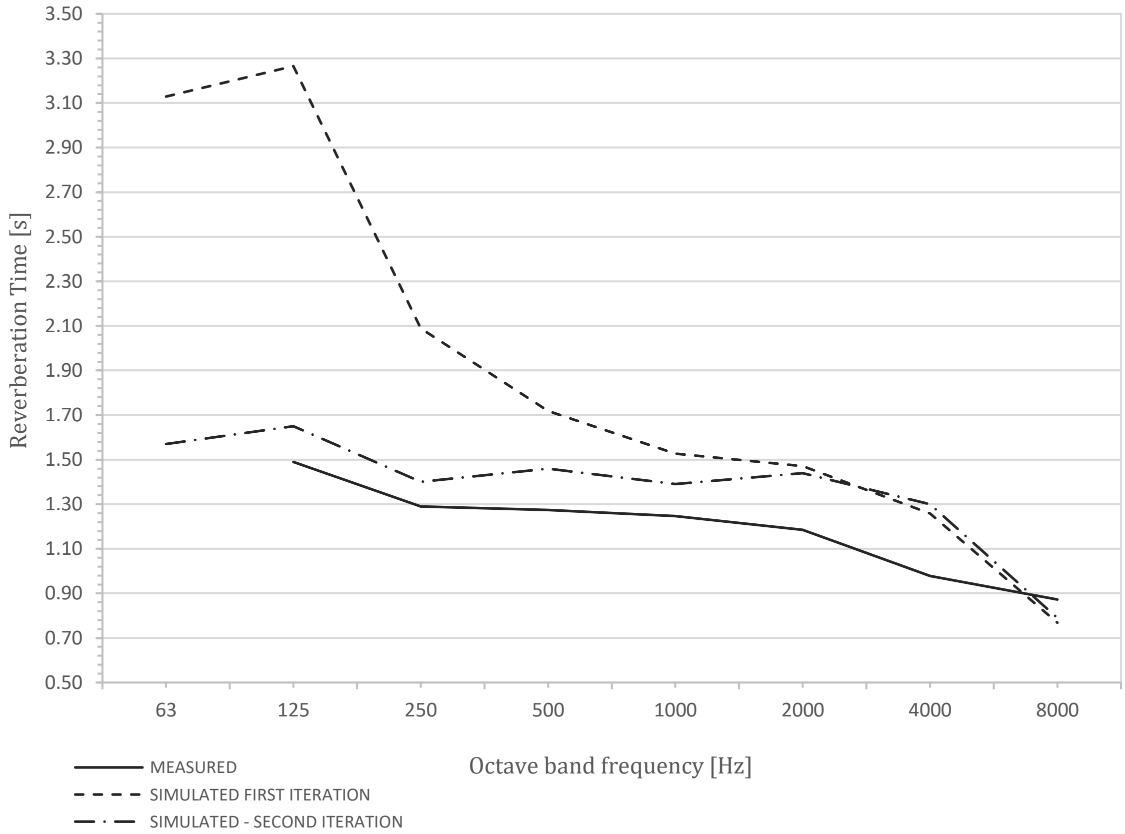

Figure 35 Simulated and measured mean RT in unoccupied Kasino am Schwarzenbergplatz

The following table lists the surfaces that are used to model the geometry in Odeon and their areas. The first set of materials assigned to these surfaces is also presented together with the absorption coefficients in octave-band frequencies (Table 13 –

Iteration I). The changes in materials and correspondingly in absorption coefficients during the calibration of the simulated model are presented in the same table (Iteration II). All materials used in the simulation model were taken from the material library that the software provides.

Table 13 Surface areas and material absorption coefficients by frequency band for the materials used in the simulation of Kasino am Schwarzenbergplatz

Surface	**Area [m²]**	**Itera tion**	**Finish materials**	**Sound absorption coefficient by frequency band (α)**							
				63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Ceiling	1033	I	Painted plaster surface	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
		II	Plaster, gypsum or lime, rough finish on lath	0.14	0.14	0.10	0.06	0.05	0.04	0.03	0.03
Gallery walls	400	I	Painted plaster surface	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
		II	Concrete block,with or without plaster	0.11	0.11	0.08	0.07	0.06	0.05	0.05	0.05
Walls	525	I,II	Concrete block, with or without plaster	0.11	0.11	0.08	0.07	0.06	0.05	0.05	0.05
Walls	325	I,II	Marble or glazed tile	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
Window blinds	113.2	I,II	Blinds	0.18	0.18	0.08	0.14	0.22	0.37	0.34	0.34
Windows	113.2	I,II	Double glazing	0.1	0.1	0.07	0.05	0.03	0.02	0.02	0.02
Curtains	75.7	I,II	Cotton cloth	0.07	0.07	0.31	0.49	0.81	0.66	0.54	0.54
Furniture	27	I	Linoleum or vinyl stuck to concrete	0.02	0.02	0.02	0.03	0.04	0.04	0.05	0.05
		II	Plaster with wallpaper on backing paper	0.02	0.02	0.03	0.04	0.05	0.07	0.08	0.08
	28.5	I	Perforated polyester cloth	0.01	0.01	0.03	0.05	0.30	0.65	0.50	0.50
	4.7	II	Perforated polyester cloth	0.01	0.01	0.03	0.05	0.30	0.65	0.50	0.50
	23.8		Hollow wooden podium	0.40	0.40	0.30	0.20	0.17	0.15	0.10	0.10
Drapes	348	I,II	Heavy velour	0.14	0.14	0.35	0.55	0.72	0.70	0.65	0.65
Floor	525	I,II	Wooden floor on joists	0.15	0.15	0.11	0.10	0.07	0.06	0.07	0.07
Audience floor	190	I	Wooden floor on joists	0.15	0.15	0.11	0.10	0.07	0.06	0.07	0.07
		II	Hollow wooden podium	0.40	0.40	0.30	0.20	0.17	0.15	0.10	0.10
Audience seats	57	I,II	Upholstered chairs with cloth cover	0.44	0.44	0.60	0.77	0.89	0.82	0.70	0.70
Doors	17.6	I,II	Solid wooden door	0.14	0.14	0.10	0.06	0.08	0.10	0.10	0.10

The following graphs present the SPL(A) and the SPL(A) drop values after the second iteration of the simulation (Figure 36 and 37). The results of the simulations are presented next to the measured SPL(A) and SPL(A) drop values previously seen in Section 3.1.2.

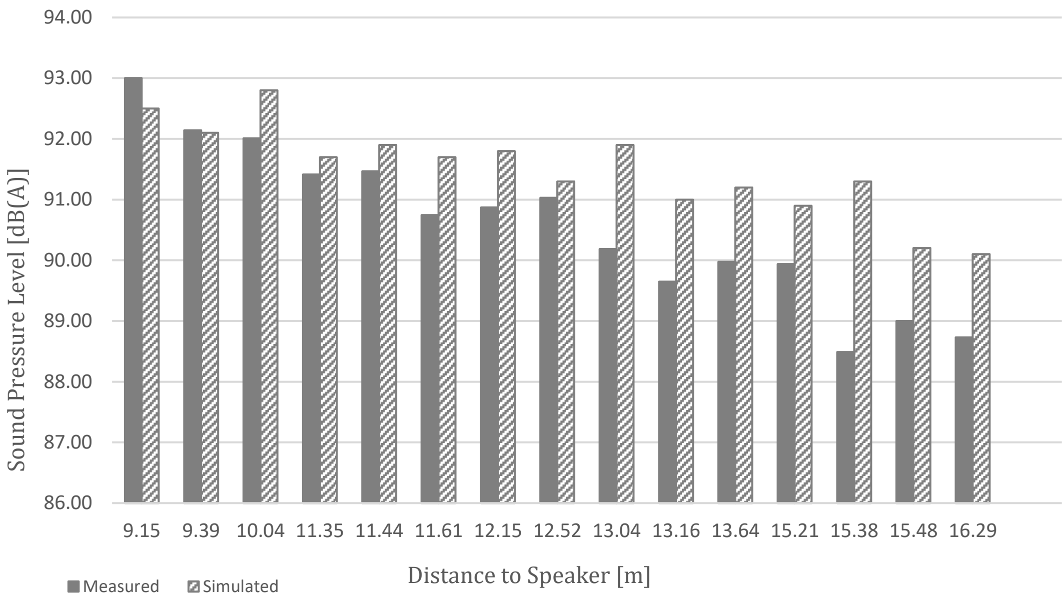

Figure 36 Simulated and measured SPL(A) in Kasino am Schwarzenbergplatz

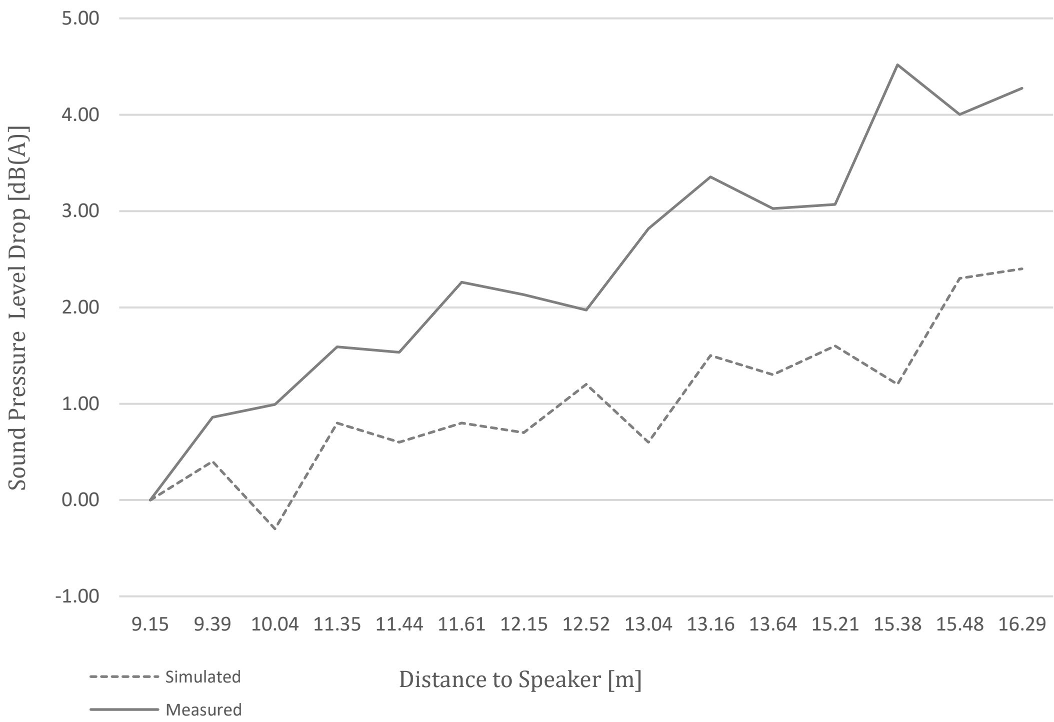

Figure 37 Simulated and measured SPL(A) drop over distance in Kasino am Schwarzenbergplatz

3.2.3 Kuppelsaal

The following table and graph present the calculated RT values in the simulated model (Table 14, Figure 38). They contain the results of the first and second iteration as well as the results of the measured RT previously shown in Section 3.1.3.

Table 14 Measured and simulated mean RT values by frequency band in unoccupied Kuppelsaal

Kuppelsaal	RT by frequency band [s]							
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Measured	1.43	1.39	1.47	1.21	1.15	1.08	0.93	0.69
Simulated (Iteration I)	0.79	0.74	1.48	1.84	2.32	2.33	1.88	1.01
Simulated (Iteration II)	1.68	1.59	1.16	1.21	1.13	1.07	1.09	0.70

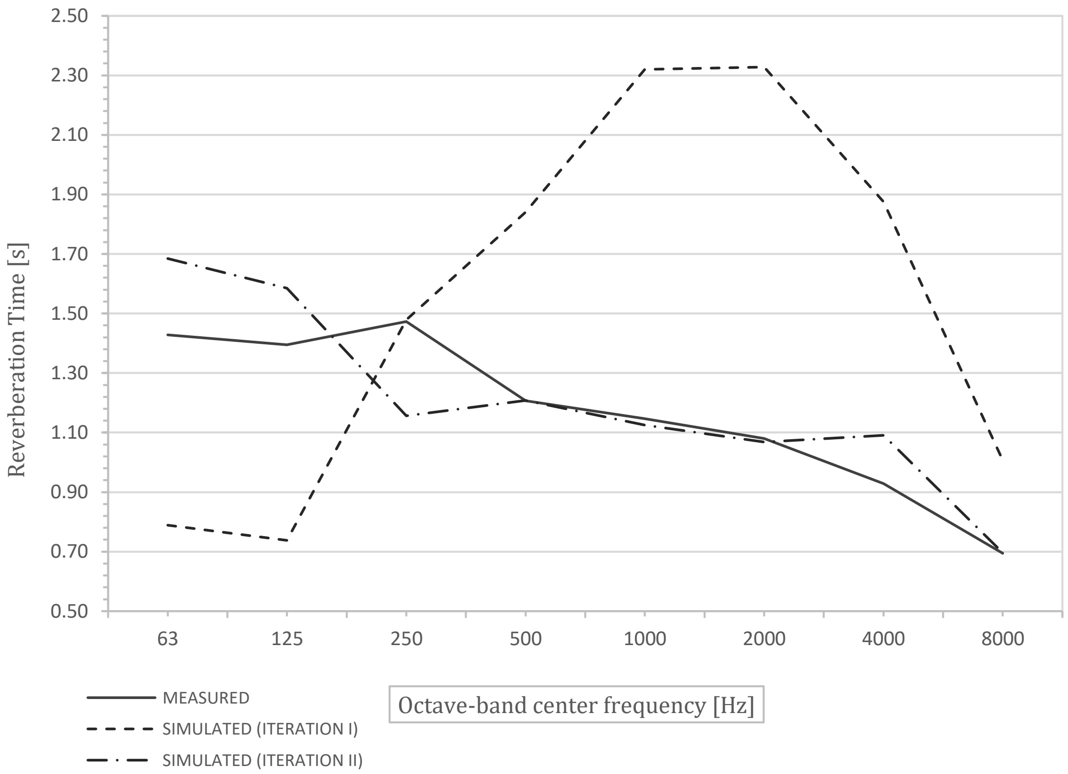

Figure 38 Simulated and measured mean RT in unoccupied Kuppelsaal

The following table lists the surfaces that are used to model the geometry of Kuppelsaal in Odeon and their areas (Table 15). Following the principle of Table 13 the set of materials assigned during the first and second iteration are presented.

Table 15 Surface areas and material absorption coefficients by frequency band for the materials used in Kuppelsaal

Surface	Area [m²]	Iteration	Finish materials	Sound absorption coefficient by frequency band (α)							
				63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Walls	300	I,II	Concrete block, with or without plaster	0.11	0.11	0.08	0.07	0.06	0.05	0.05	0.05
Windows	37.1	I,II	Ordinary window glass	0.35	0.35	0.25	0.18	0.12	0.07	0.04	0.04
Floor	384.9	I	Floating wooden floor	0.10	0.10	0.07	0.05	0.06	0.06	0.06	0.06
		II	Wood parquet in asphalt on concrete	0.04	0.04	0.04	0.07	0.06	0.06	0.07	0.07
Ceiling	851.5	I	Plywood panelling	0.28	0.28	0.22	0.17	0.09	0.10	0.11	0.11
		II	Combination of porous absorbers and vibrating plates	0.17	0.17	0.41	0.43	0.48	0.5	0.5	0.5
Arcs	1049.2	I	Plywood on battens fixed to solid backing	0.30	0.30	0.20	0.15	0.13	0.10	0.08	0.08
		II	Periodic battens	0.07	0.07	0.11	0.11	0.10	0.10	0.02	0.06
Furniture (Perimetral seating)	145.35	I	Wood, 25mm with air space	0.19	0.19	0.14	0.09	0.06	0.06	0.05	0.05
		II	Hollow wooden podium	0.40	0.40	0.30	0.20	0.17	0.15	0.10	0.10
Doors	47.4	I,II	Solid wooden door	0.14	0.14	0.10	0.06	0.08	0.10	0.10	0.10
Audience seats	79.7	I,II	Wooden chairs, empty	0.05	0.05	0.05	0.05	0.10	0.10	0.15	0.15

The next graph presents the SPL(A) and SPL(A) drop values calculated on the second iteration of the simulation of the model (Figure 39 and 40). The results of the simulations are presented next to the measured SPL(A) and SPL(A) drop values previously seen in Section 3.1.3.

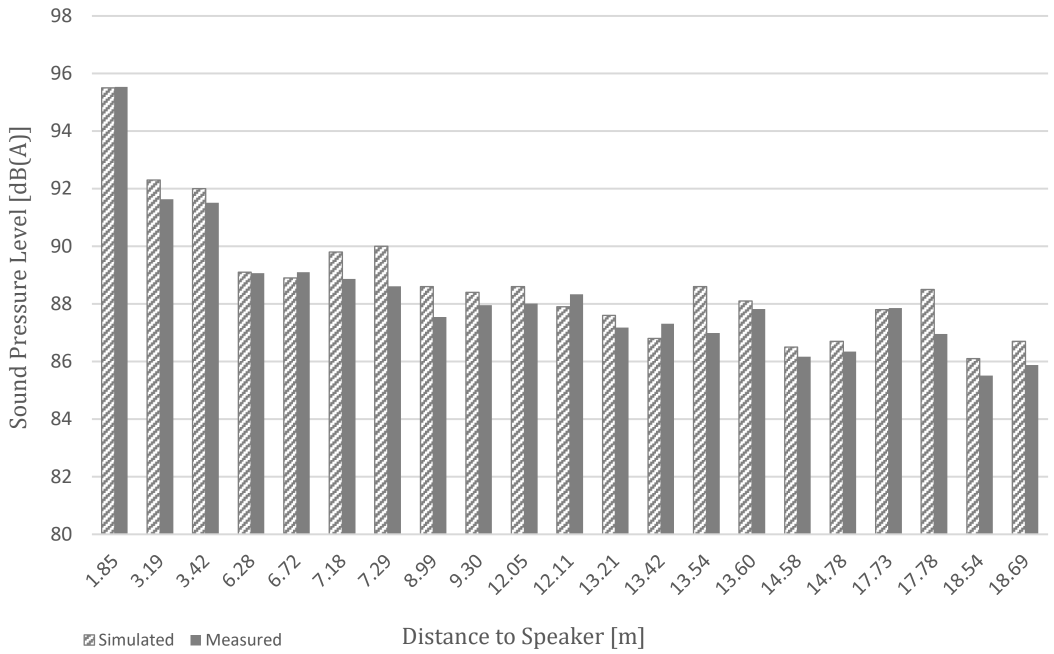

Figure 39 Simulated and measured SPL(A) in Kuppelsaal

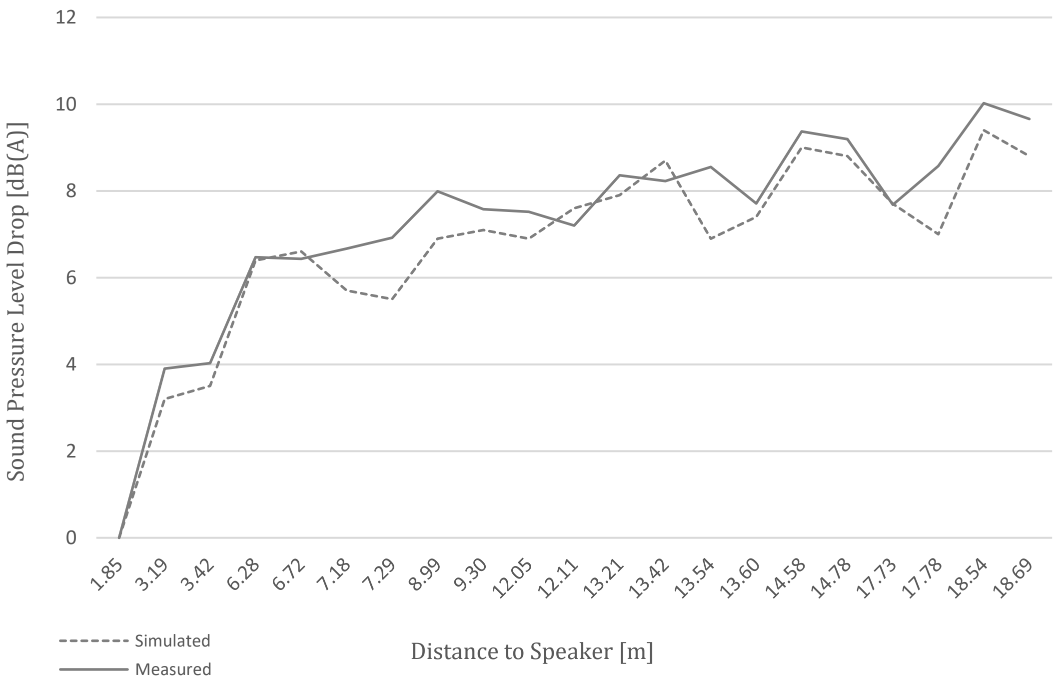

Figure 40 Simulated and measured SPL(A) drop over distance in Kuppelsaal

3.2.4 Rote Bar

The following table and graph present the calculated RT values in the simulated model (Table 16, Figure 41). They contain the results of the first iteration and the second one. The graph also shows the results of the measured RT previously shown in Figure 21.

Table 16 Measured and simulated mean RT values by frequency band in unoccupied Rote Bar

Rote Bar	RT by frequency band [s]							
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Measured	/	2.30	1.36	1.03	0.94	0.93	0.84	0.67
Simulated (Iteration I)	/	2.53	1.72	1.64	1.43	1.20	1.20	0.72
Simulated (Iteration II)	/	2.35	1.49	1.37	1.16	1.11	1.02	0.71

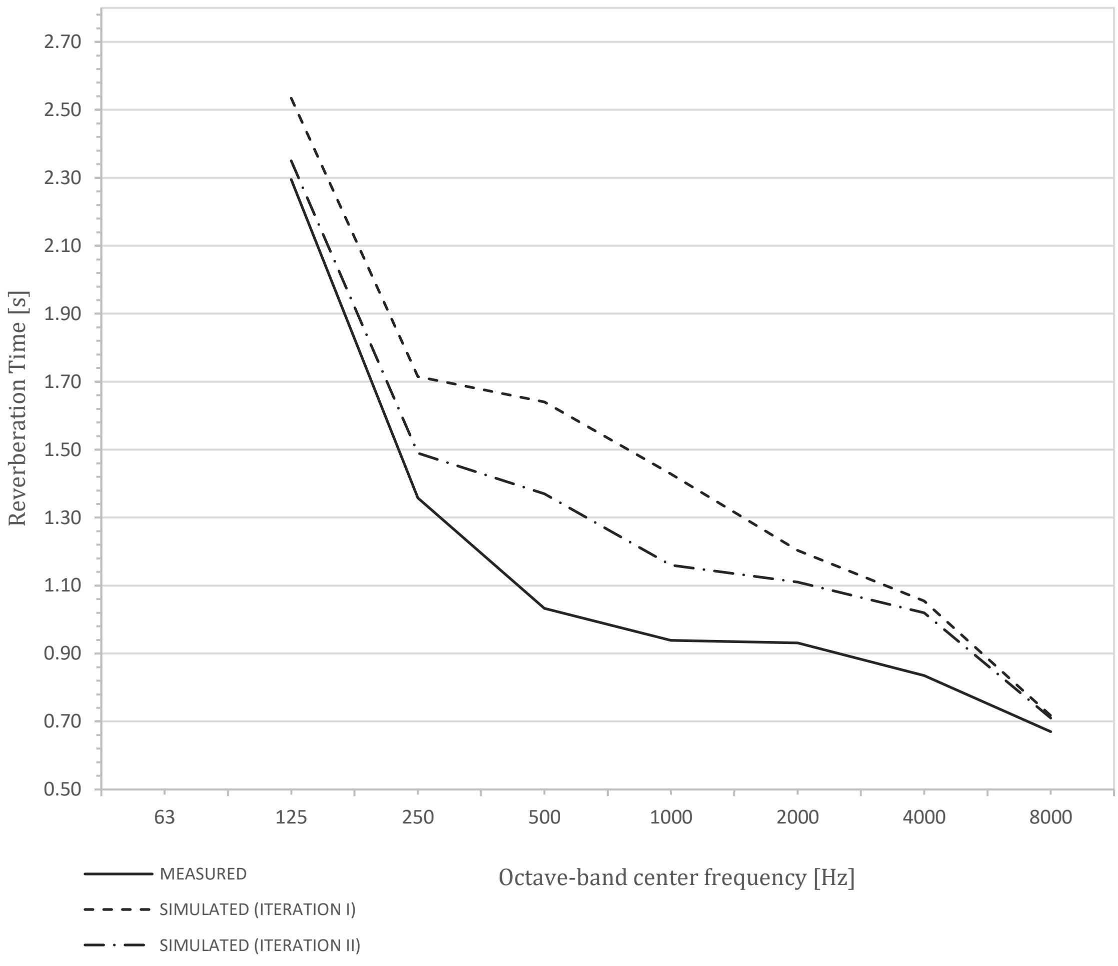

Figure 41 Simulated and measured mean RT in unoccupied Rote Bar

The following table lists the surfaces that are used to model the geometry of Rote Bar in Odeon and the corresponding areas (Table 17). The set of materials assigned to these surfaces is also presented together with the absorption coefficients in octave-band frequencies. Similar to the previous case studies, this model was also simulated in two iterations. In this case the difference between the two iterations was not a change of a material but a change of a property of the surface in Odeon, which will be discussed later in this paper.

Table 17 Surface areas and material absorption coefficients by frequency band for the materials used in Rote Bar

Surface	**Area [m²]**	**Iteration**	**Finish materials**	**Sound absorption coefficient by frequency band (α)**							
				63 **Hz**	125 **Hz**	250 **Hz**	500 **Hz**	1000 **Hz**	2000 **Hz**	4000 **Hz**	8000 **Hz**
Walls	400	I,II	Painted plaster surface	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	24.3		Plaster with wallpaper on backing paper	0.02	0.02	0.03	0.04	0.05	0.07	0.08	0.08
Ceiling	242.7	I,II	Smooth concrete, painted or glazed	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Windows	32.8	I,II	Double glazing	0.1	0.1	0.07	0.05	0.03	0.02	0.02	0.02
Window blinds	1.7	I,II	Blinds	0.18	0.18	0.08	0.14	0.22	0.37	0.34	0.34
Floor	169	I,II	Marble or glazed tile	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
Curtains	14.9	I,II	Cotton cloth	0.07	0.07	0.31	0.49	0.81	0.66	0.54	0.54
Drapes	227	I,II	Heavy velour	0.14	0.14	0.35	0.55	0.72	0.70	0.65	0.65
Carpet (Stage)	40	I,II	Carpet heavy, on concrete	0.02	0.02	0.06	0.14	0.37	0.60	0.65	0.65
Doors	1.6	I,II	Solid wooden door	0.14	0.14	0.10	0.06	0.08	0.10	0.10	0.10
Furniture	27	I,II	Glaze plaster	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02
Audience seats	24.6	I,II	Upholstered chairs with cloth cover	0.44	0.44	0.60	0.77	0.89	0.82	0.70	0.70

The next graphs are a presentation of the SPL(A) and SPL(A) drop values calculated on the second iteration of the simulated model of Rote Bar (Figure 42 and 43). The results of the simulations are shown next to the measured SPL(A) and SPL(A) drop values previously seen in Section 3.1.4.

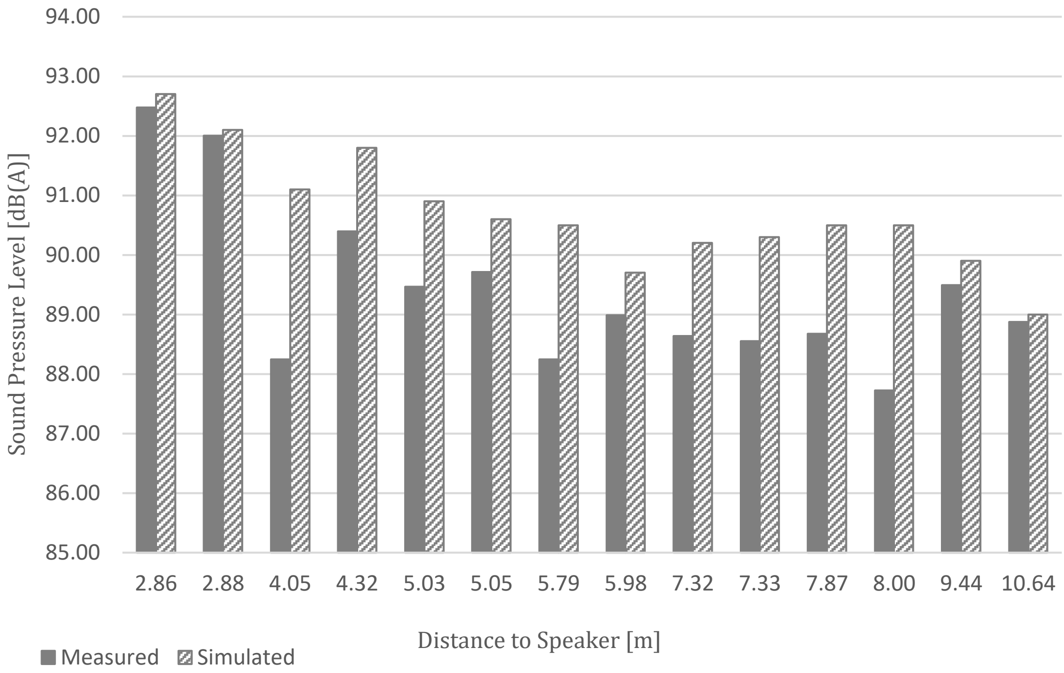

Figure 42 Simulated and measured SPL(A) in Rote Bar

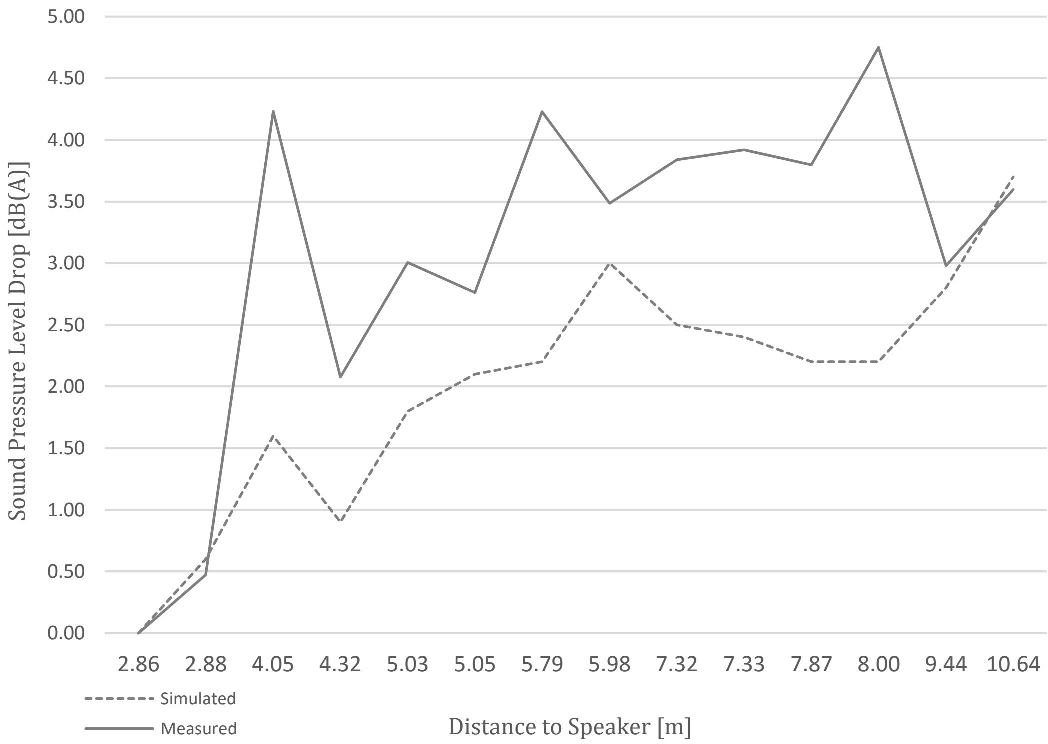

Figure 43 Simulated and measured SPL(A) drop over distance in Rote Bar

3.3 Simulations with an audience

- ### Halle E

Table 18 Simulated mean RT values in unoccupied and occupied Halle E

Halle E	**RT by frequency band [s]**							
	63 **Hz**	125 **Hz**	250 **Hz**	500 **Hz**	1000 **Hz**	2000 **Hz**	4000 **Hz**	8000 **Hz**
Measured	2.45	1.87	1.86	1.96	1.86	1.67	1.33	1.07
Simulated (unoccupied)	2.15	2.19	1.97	1.81	1.87	1.89	1.57	0.90
Simulated (occupied)	2.15	2.19	1.97	1.80	1.86	1.88	1.56	0.90

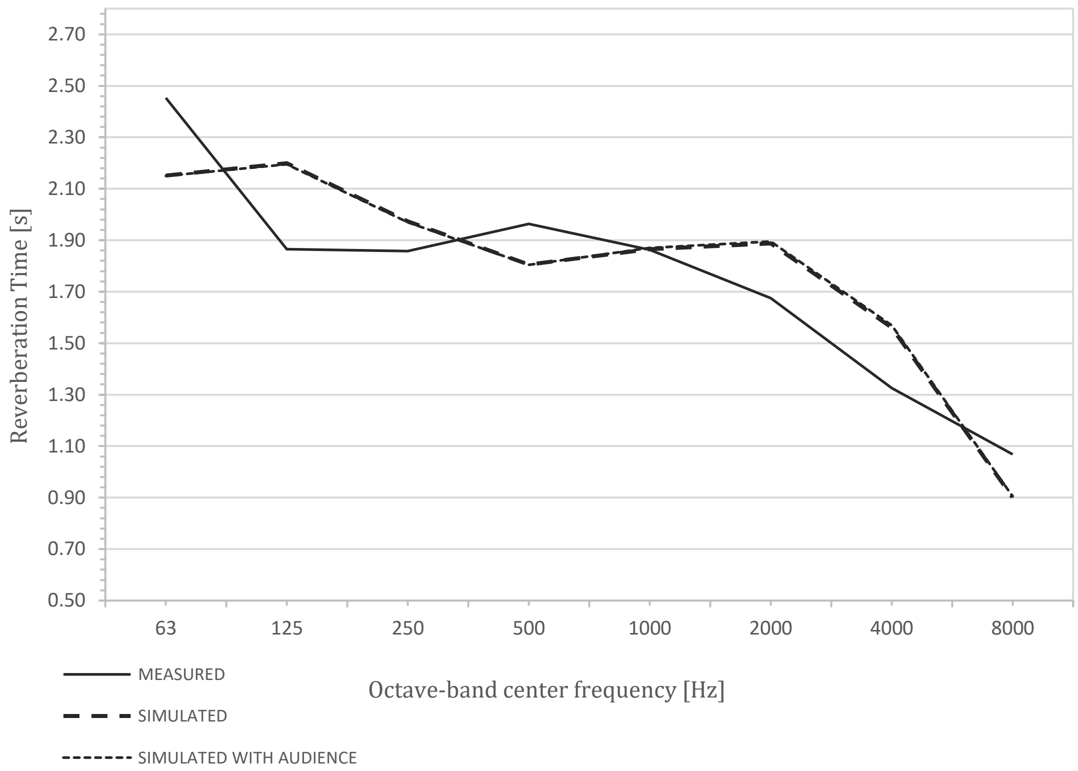

Figure 44 Simulated RT in occupied and unoccupied Halle E

Table 19 Surface areas and material absorption coefficients by frequency band for the materials used for unoccupied and occupied auditorium in Halle E

Surface	**Area [m²]**	**Iteration**	**Finish materials**	**Sound absorption coefficient by frequency band (α)**							
				63 **Hz**	125 **Hz**	250 **Hz**	500 **Hz**	1000 **Hz**	2000 **Hz**	4000 **Hz**	8000 **Hz**
Audience	335	Not occupied	Heavily upholstered chairs	0.72	0.72	0.79	0.83	0.84	0.83	0.79	0.79
		Occupied	Audience, heavily upholstered seats	0.72	0.72	0.8	0.86	0.89	0.9	0.9	0.9

- **Kasino am Schwarzenbergplatz**

Table 20 Simulated mean RT values in unoccupied and occupied Kasino am Schwarzenbergplatz

Kasino	RT by frequency band [s]							
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Measured	/	1.49	1.29	1.27	1.25	1.19	0.98	0.87
Simulated (unoccupied)	1.57	1.65	1.40	1.46	1.39	1.44	1.30	0.79
Simulated (occupied)	1.58	1.62	1.38	1.46	1.40	1.43	1.28	0.78

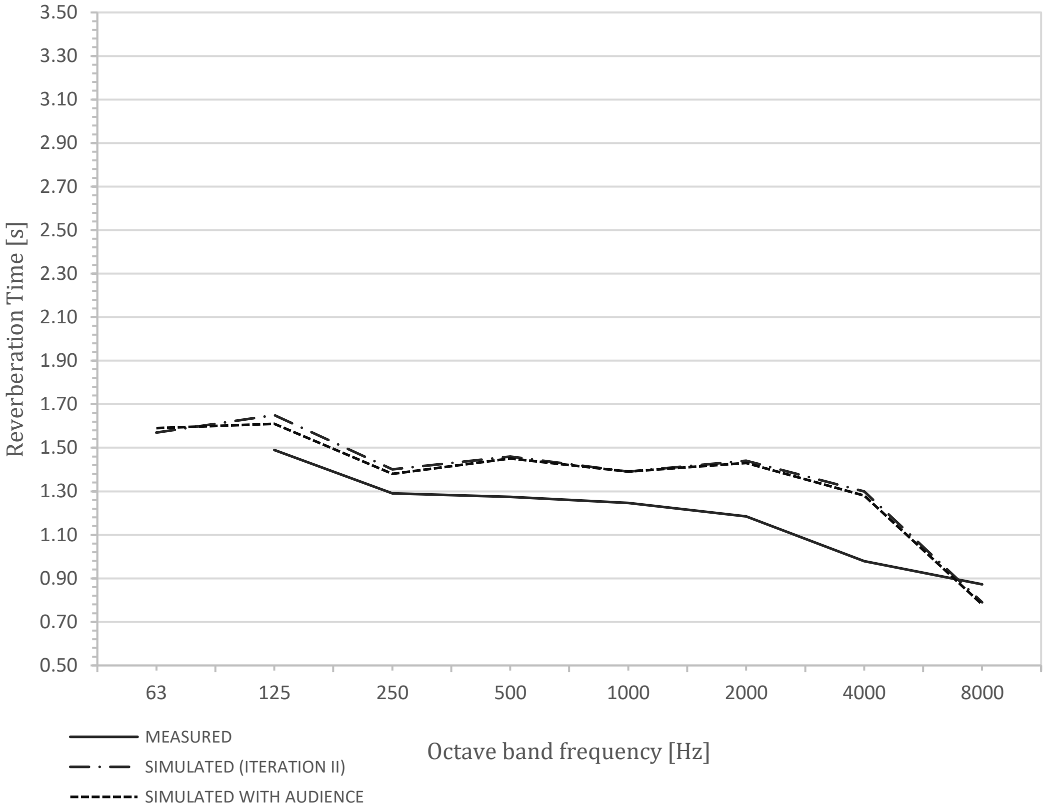

Figure 45 Simulated RT in occupied and unoccupied Kasino am Schwarzenbergplatz

Table 21 Surface areas and material absorption coefficients by frequency band for the materials used for unoccupied and occupied auditorium in Kasino am Schwarzenbergplatz

Surface	Area [m²]	Iteration	Finish materials	Sound absorption coefficient by frequency band (α)							
				63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Audience	57	Not occupied	Upholstered chairs with cloth cover	0.44	0.44	0.60	0.77	0.89	0.82	0.70	0.70
		Occupied	Audience on upholstered chairs	0.62	0.62	0.72	0.80	0.83	0.84	0.85	0.85

- **Kuppelsaal**

Table 22 Simulated mean RT values in unoccupied and occupied Kuppelsaal

Kuppelsaal	RT by frequency band [s]							
	63 **Hz**	125 **Hz**	250 **Hz**	500 **Hz**	1000 **Hz**	2000 **Hz**	4000 **Hz**	8000 **Hz**
Measured	1.43	1.39	1.47	1.21	1.15	1.08	0.93	0.69
Simulated (unoccupied)	1.68	1.59	1.16	1.21	1.13	1.07	1.09	0.70
Simulated (occupied)	1.47	1.43	1.04	1.08	1.01	0.96	1	0.65

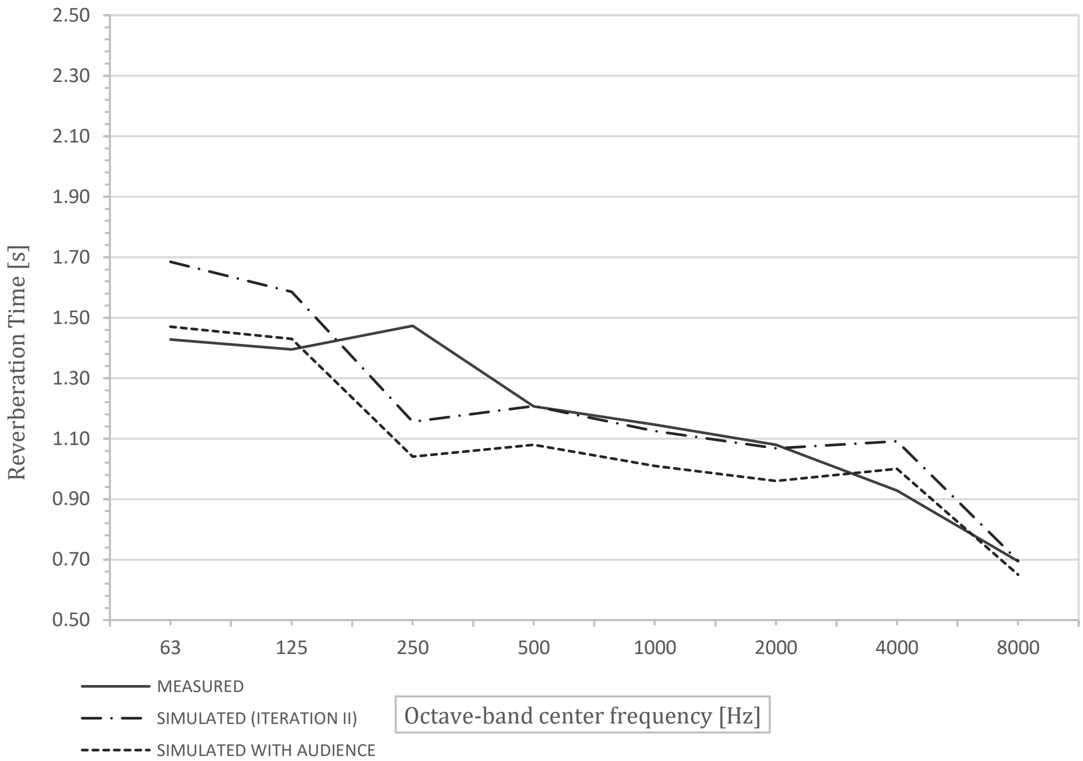

Figure 46 Simulated mean RT in occupied and unoccupied Kuppelsaal

Table 23 Surface areas and material absorption coefficients by frequency band for the materials used for unoccupied and occupied auditorium in Kuppelsaal

Surface	**Area [m²]**	**Iteration**	**Finish materials**	**Sound absorption coefficient by frequency band (α)**							
				63 **Hz**	125 **Hz**	250 **Hz**	500 **Hz**	1000 **Hz**	2000 **Hz**	4000 **Hz**	8000 **Hz**
Audience	79.7	Not occupied	Wooden chairs, empty	0.0 5	0.05	0.05	0.05	0.10	0.10	0.15	0.15
		Occupied	Audienc e on wooden chairs	0.40	0.40	0.60	0.75	0.80	0.85	0.80	0.80

- **Rote Bar**

Table 24 Simulated mean RT values in unoccupied and occupied Rote Bar

Rote Bar	RT by frequency band [s]							
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Measured	/	2.30	1.36	1.03	0.94	0.93	0.84	0.67
Simulated (unoccupied)	/	2.35	1.49	1.37	1.16	1.11	1.02	0.71
Simulated (occupied)	/	2.34	1.46	1.35	1.16	1.09	0.99	0.69

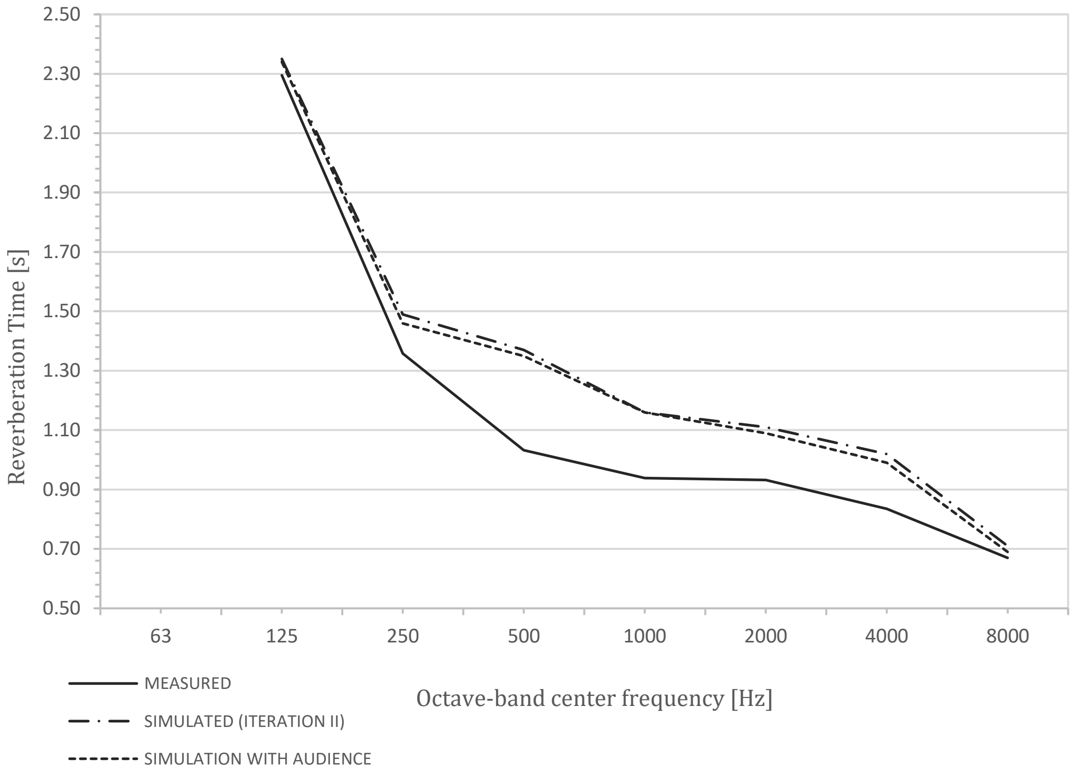

Figure 47 Simulated mean RT in occupied and unoccupied Rote Bar

Table 25 Surface areas and material absorption coefficients by frequency band for the materials used for unoccupied and occupied auditorium in Rote Bar

Surface	Area [m²]	Iteration	Finish materials	Sound absorption coefficient by frequency band (α)							
				63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Audience	24.6	Not occupied	Upholstered chairs with cloth cover	0.44	0.44	0.60	0.77	0.89	0.82	0.70	0.70
		Occupied	Audience on upholstered chairs	0.62	0.62	0.72	0.80	0.83	0.84	0.85	0.85

4 COMPARISON AND DISCUSSION

- **Overview**

This chapter compares the measurement results with the simulation results. The re-evaluation process of the first material assumptions is interpreted and a further explanation for the choice of material properties during the calibration of the models is given. Finally their effect on the final result is elaborated. In addition, an evaluation of a purpose-dependent performance based on the volume and the mid-frequency RT in each of the halls is made followed by an overview of the SPL and the sound distribution in the halls.

- **Halle E**

As presented in Table 10, the simulated results of the RT in Halle E show an overestimated RT in comparison to the measured results in the lower frequencies at 125 and 250 Hz and in the higher frequencies at 2000 and 4000 Hz. At 500 Hz the simulated RT is slightly underestimated, whereas at 1000 Hz it corresponds to the measured RT.

The long RT in Halle E is in big part due to the big area of highly reflecting boundary surfaces such as the painted plaster walls and the reflecting wooden floor. The elements with the highest absorbing properties which are bringing the performance of the room somehow to a balance are the heavily upholstered chairs, whereas the curtains and the drapes are contributing mostly to the absorption in higher frequencies.

- **Kasino am Schwarzenbergplatz**

The first iteration of the simulated model of Kasino am Schwarzenbergplatz showed significantly overestimated RT in the lower frequencies (see: Table 12). On the second iteration, after re-evaluating the choice of materials, attention was put into the material used for the flooring of the auditorium, namely the material '*Wooden floor on joists (Ingerslev, 1949)*' from the Odeon Material library. It is important to point out that Odeon by default sets all surface's Transmission type to 'Normal', which means that it sets the surfaces to surfaces which do not transmit sound to another room, meaning that it results in not considering any transmission properties of the material, therefore any surface that is behind, below or above a boundary surface does not affect the rays inside the room. In the case of the auditorium, which is modelled as a boundary surface, in reality there is clearly a construction which holds the wooden floor. In this case the space below the wooden material of the auditorium floor is important.

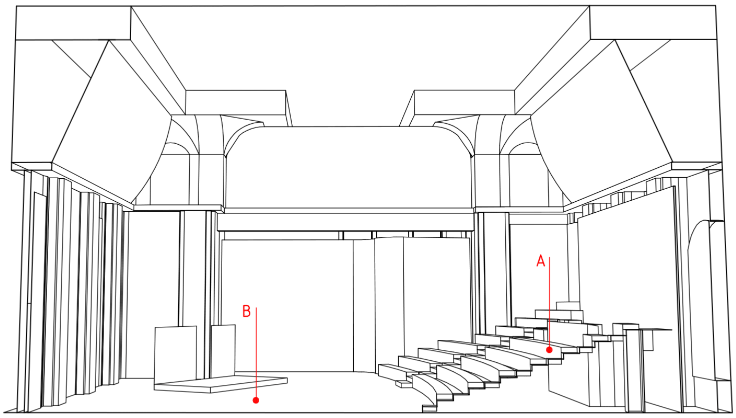

*Figure 48 Perspective section of Kasino am Schwarzenbergplatz. (**A**) Auditorium podium (**B**) Stage area*

This can be solved in two methods: the first one would be to go back to the 3D model and model the construction below the auditorium flooring, re-import the model into Odeon, assign materials to the construction and to the flooring and then set the Transmission type of the auditorium floor surfaces from 'Normal' to 'Transmission', meaning that the rays hitting the auditorium floor would then be able to be transmitted and the boundary surfaces in that case would be the surfaces below the wooden podium. The second solution, which is the one used in this case, is to change the material assigned to the boundary surface into one that already contains the property of such a construction. Namely, on the second iteration of the simulation the assigned material on the surface of the auditorium floor was changed from '*Wooden floor on joists (Ingerslev, 1949)*' to '*Hollow wooden podium (Ref. Dalenbäck, CATT)*'. The comparison between the first and the second iteration immediately shows that the change of the auditorium floor material has significantly changed the RT in the lower frequencies, bringing the simulation results closer to the measurement results. On the other hand, the second significant change made in the second iteration in comparison to the first one is the change of the ceiling material. The change from '*Painted plaster surface (Kristensen, 1984)*' to material '*Plaster, gypsum, or lime, rough finish on lath*

(Harris, 1991)' has also improved the results of the second iteration, bringing the overall RT of the simulation results into lower values and coming to a better agreement with the measurement results. This means that assigning a material such as '*Plaster, gypsum, or lime, rough finish on lath (Harris, 1991)'* may be more accountable as a 'false ceiling' which is a more appropriate assumption for the construction of the building than simply using a painted plaster surface.

The materials contributing to the absorption area in the mid-frequencies are the drapes, the cotton cloth curtains and the heavily upholstered chairs, out of which the drapes have the biggest contribution as they represent the biggest area out of all three. On the other hand the reverberance of the room is in the biggest part a result of the high-reflecting marble walls and the plaster walls and ceiling.

- **Kuppelsaal**

The first iteration of the simulation of Kuppelsaal show an underestimated RT in the lower frequencies and a significantly overestimated RT in the higher frequencies (see: Table 14). In the first iteration all materials used in the simulation model are part of the material library provided by the software.

As the main elements that contribute to the RT behaviour of Kuppelsaal are the ceiling and the arcs, it was reasonable to calibrate the model by re-evaluating the first material assumptions assigned to them. The material assigned to the arcs in the first iteration is *'Plywood on battens fixed to solid backing (Ref. Dalenbäck, CATT)'* which in the second iteration is changed to *'Periodic battens (Choi, 2013)'*. This change results in an increase of RT in the lower frequencies and is in better agreement with the measurement results.

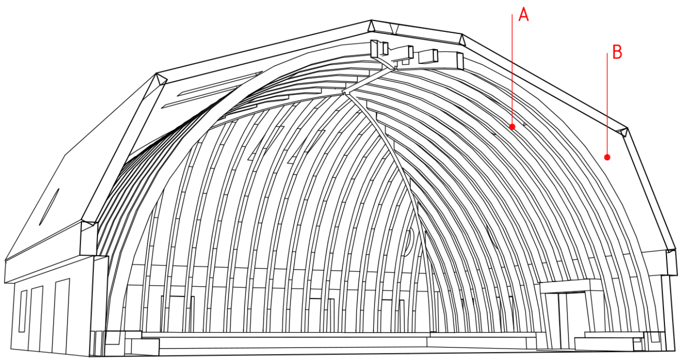

*Figure 49 Perspective section of Kuppelsaal (**A**) Arcs (**B**) Ceiling behind arcs*

On the other hand, the ceiling seems to have a very big impact on RT in the higher frequencies. In the first iteration the material assigned to the ceiling is *'Plywood paneling, 1 cm thick (Harris, 1991)'*, which is a material relatively absorbing in the lower frequencies with α values between 0.22-0.28, but without significant absorptive properties in the higher frequencies. In the second iteration the material is changed to a custom created material from a combination of porous absorbers and vibrating plates (Figure 50).

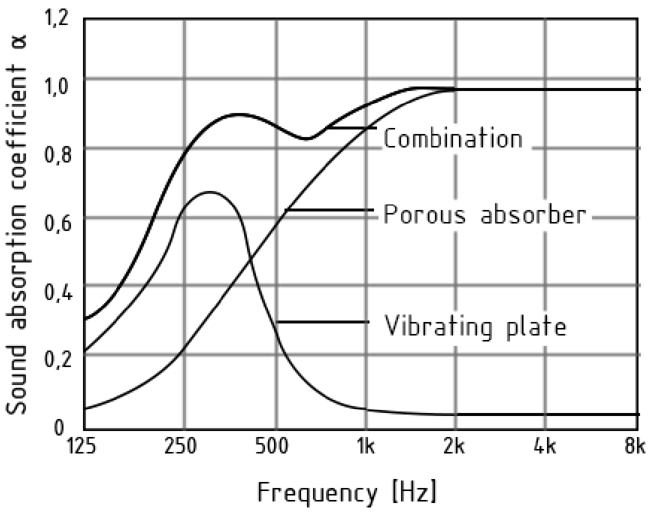

Figure 50 Absorption coefficients of a combination of porous absorber and vibrating plate (adapted from source: Fasold and Veres, 2003. Pp.96)

As in reality there is no material where α=1, we have taken the values of Figure 39 and lowered the α values by 50% (see: Table 15) .The custom created material was then added to the Odeon material library. After the run of the second iteration, we see that this change of the material significantly changes the overall RT of the hall but specifically contributes to lowering the RT values in the higher frequencies. This brings the results of the second iteration to a significantly better agreement with the measurement results, which means that this material comes closer to the real construction. Therefore in this case using a simple material to describe the ceiling, such as plywood paneling, has resulted in misleading results in the first iteration.

- **Rote Bar**

The results of the first iteration of Rote Bar show overestimated RT in the overall range of frequencies (Table 16). After the first iteration was run, it was noticed that due to the non-transmission type of the surface assigned to the drapes dividing the main hall and the entrance hall, the drapes are considered as the boundary surface, therefore the rays are not transmitted to the entrance hall, which is not the case not only in reality, but also in the model, where the entrance hall is indeed modelled and is supposed to be part of the assessment. Therefore, in the second iteration the surface type of these drapes is changed from 'Normal' to 'Transmission', and the rays are then able to be transmitted into the entrance hall (Figure 51).

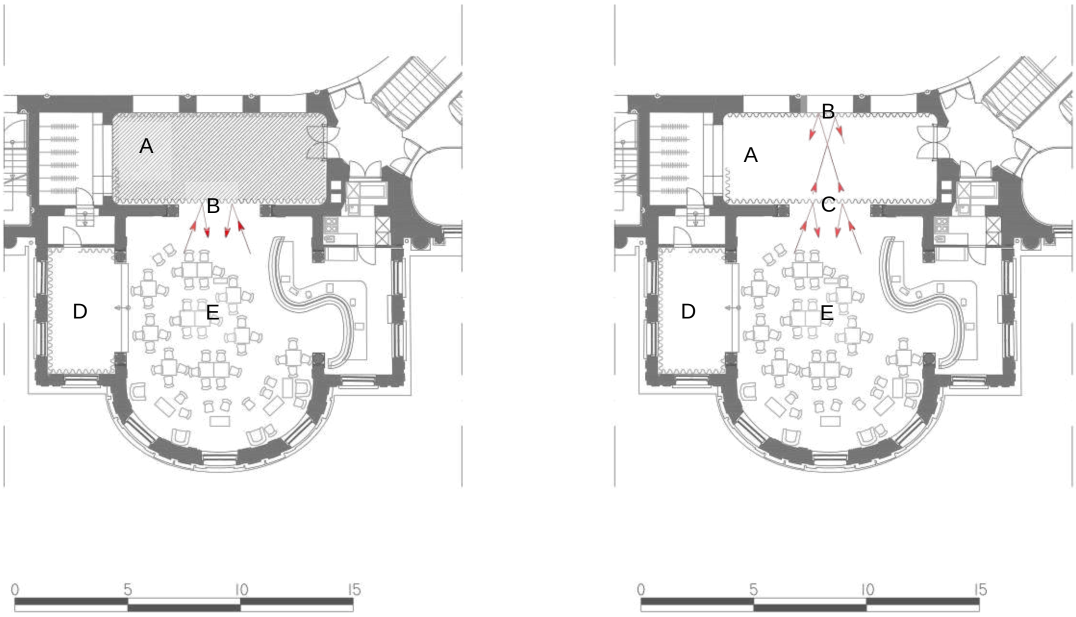

*Figure 51 Drapes between the main and the entrance hall in Rote Bar (**A**) Entrance hall (**B**) Drapes as surface boundaries (**C**) Drapes with transmission property (**D**) Stage (**E**) Audience*

Furthermore, in the upper part of the entrance wall there are three openings that are open to the gallery which connects the Rote Bar to the main corridor of the upper floor from where the main theatre hall can be accessed. The central opening, which is the biggest one, is closed with the same drapes as the ones inside the hall, whereas the two side, oval-shaped openings are open to the gallery and are not closed with any drapes. The upper gallery is not part of the model of Rote Bar, therefore these three openings, just like the wall, represent surface boundaries of the room. In the first iteration, all three of them are assigned a curtain material, respectively the Odeon material *'Drapes, heavy velour (Harris, 1991)' (Figure 52).*

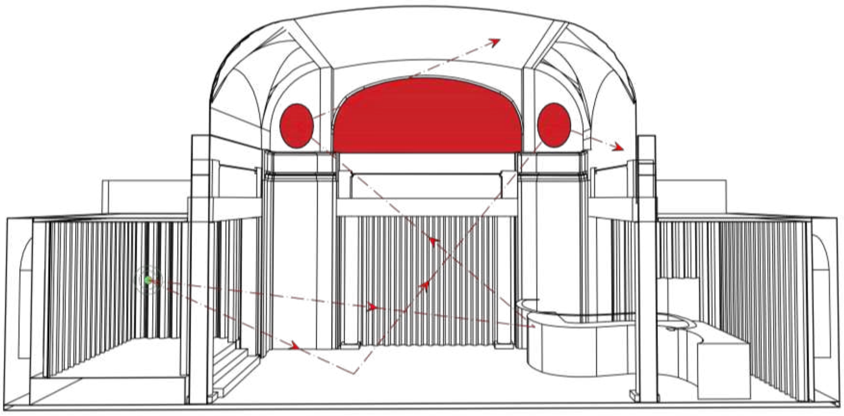

Figure 52 The openings on the first iteration of the Rote Bar modelled as surface boundaries with material 'Drapes, heavy velour' – reflecting rays

However, this is not the real case, as the rays that go into the oval-shaped openings will not be immediately reflected as they would from a drape material. Theoretically, a transparent surface, if seen as a boundary surface, is 100% absorbent. Therefore, in the second iteration the material assigned to the oval-shaped openings is changed to a 100% absorbing material (Figure 53).

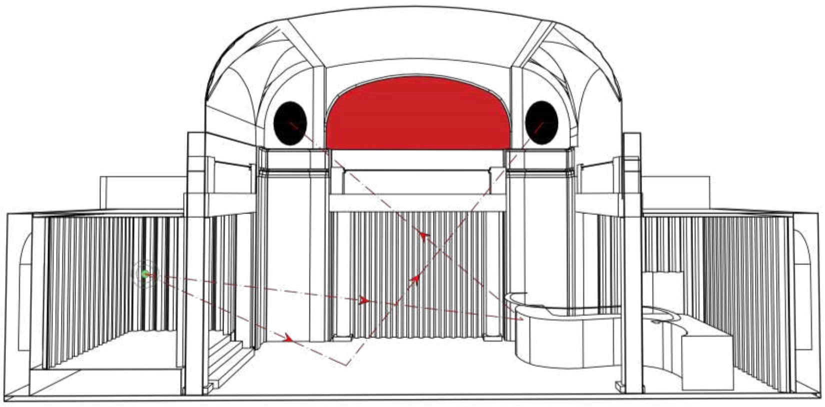

Figure 53 The openings on the second iteration of the Rote Bar as surface boundaries with material '100% absorbing' – not reflecting rays

After the run of the second iteration the simulation results show reduced RT in the overall frequency range. This means that the added volume of the entrance hall has helped with the overall absorption and is closer to the real measurements.

- **Comments on RT**

Table 26 presents an overview of all four case studies with information on the volume, seat capacity and measured mid-frequency reverberation time.

Table 26 An overview of the four case studies' volume, seat capacity and RTm

Name	Seat Capacity	Volume [m³]	Volume/Seat [m³]	RTm [s]
Halle E	872	17 000	19.5	1.80
Kasino am Schwarzenbergplatz	250	3880	15.5	1.46
Kuppelsaal	300	3420	11.4	1.08
Rote Bar	60	1225	20.4	1.35

In Chapter 1 it was talked about the importance of reverberation time in the overall acoustical performance of a hall. Figure 55 presents a relationship between the 'optimum' reverberation time at 500 Hz for a particular function of the room and its volume (Fasold and Veres 2003). In addition, Figure 54 presents acceptable ranges of RT when deciding about the acoustical performance of an existing/designed room, depending on their relation to the recommended (optimal) RT (RTopt) for the given purpose of the room (Fasold and Veres, 2003).

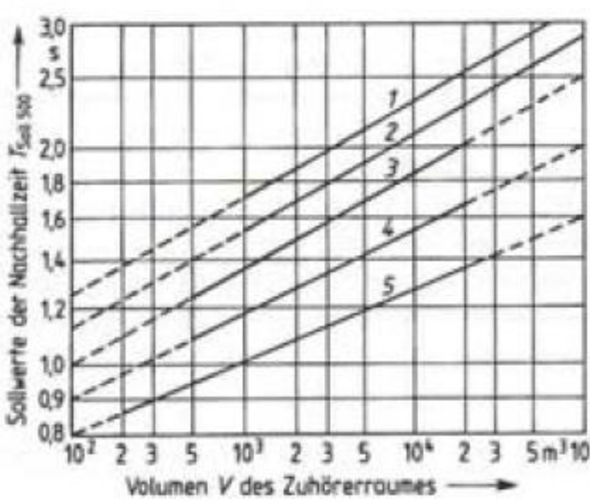

*Figure 55 Purpose and volume dependent RTm criteria (**1**)Oratory and organ music (**2**)Rooms for symphonic music (**3**)Rooms for solo and chamber music (**4**)Multipurpose halls (**5**)Speech (source: Fasold and Veres 2003)*

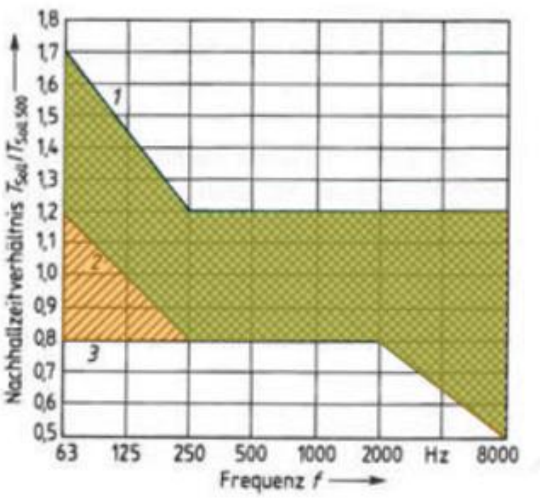

Figure 54 RT acceptable ranges (Area 1 to 2: Music, Area 1 to 3: Speech) (source: Fasold and Veres 2003)

The following figures place the volume of the four halls into the graph presented in Figure 55 to get the corresponding recommended RTm (RTopt) for symphonic music (Figure 56), solo and chamber music (Figure 57), multi-purpose halls (Figure 58) and speech (Figure 59) based on the volumes of the halls.

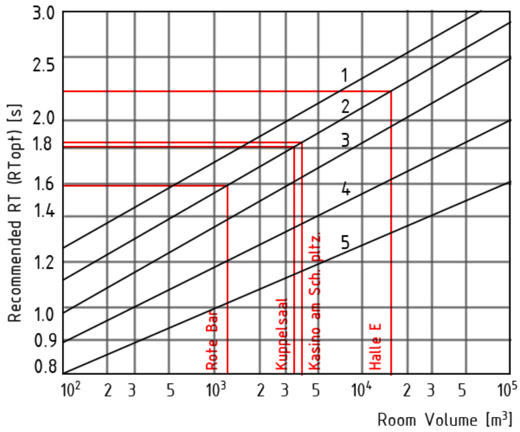

Figure 56 RTm criteria for symphonic music (adapted from source: Fasold and Veres 2003)

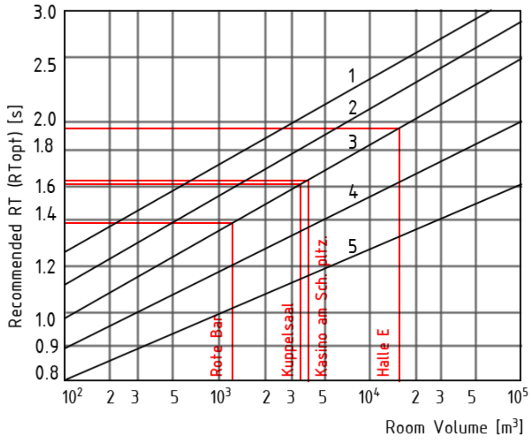

Figure 57 RTm criteria for solo and chamber music (adapted from source: Fasold and Veres 2003)

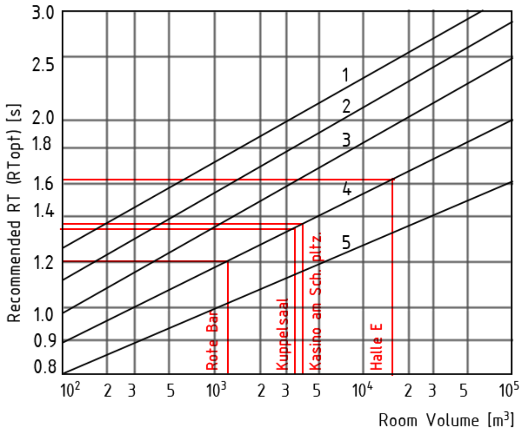

Figure 58 RTm criteria for multi-purpose halls (adapted from source: Fasold and Veres 2003)

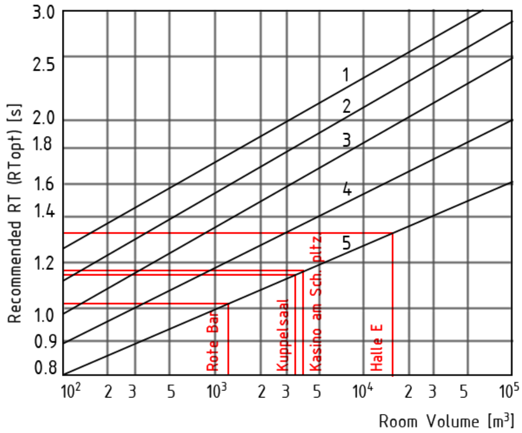

Figure 59 RTm criteria for speech (adapted from source: Fasold and Veres 2003)

The following table presents the extracted RTopt from the previous figures for the four case studies (Table 27).

Table 27 RTopt based on the volume of the four case studies, extracted from Figures 56-59

Room	RTopt [s]			
	(1) Opera house and Multipurpose rooms for music and speech	(2) Speech	(3) Solo and Chamber music	(4) Symphonic music
Halle E	1.65	1.35	1.95	2.25
Kasino am Schwarzenbergplatz	1.4	1.18	1.63	1.83
Kuppelsaal	1.38	1.16	1.61	1.8
Rote Bar	1.2	1.02	1.39	1.6

The following table presents the RT/RTopt ratio for Halle E at eight octave-band frequencies, where RT represents the simulated mean RT in occupied Halle E and RTopt is the recommended RTm, extracted from Figure 55 for the four functions presented in Table 27.

Table 28 RT/RTopt ratio for occupied Halle E. (**RT**) Simulated RT in occupied Halle E (**RTopt**) Recommended RTm for Halle E (**1**) Multipurpose rooms for speech and music (**2**) Speech (**3**) Solo and chamber music (**4**) Symphonic music

Halle E	RT by frequency band [s]							
	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Simulated RT [s]	2.15	2.19	1.97	1.80	1.86	1.88	1.56	0.90
RT/RTopt (1)	1.3	1.3	1.2	1.1	1.1	1.1	0.9	0.5
RT/RTopt (2)	1.6	1.6	1.5	1.3	1.4	1.4	1.2	0.7
RT/RTopt (3)	1.1	1.1	1.0	0.9	1	1	0.8	0.5
RT/RTopt (4)	1	1	0.9	0.8	0.8	0.8	0.7	0.4

The following figure presents the extracted RT/RTopt values from Table 28 and places them in the graph where the acceptable range of RT, previously presented in Figure 54 is shown (Figure 60).

Figure 60 shows that the simulated RT in occupied Halle E is inside the RT acceptable range for a multipurpose room at all presented frequencies. For speech the simulated RT is above the RT acceptable range, except at frequencies 63 Hz, 4000 Hz and 8000 Hz. For solo and chamber music the simulated RT is inside the RT acceptable range at all presented frequencies and for symphonic music the simulated RT is inside the RT acceptable range at all presented frequencies except at 8000 Hz where it is below the acceptable range.

In these conditions Halle E shows an optimal performance as a multi-purpose hall, whereas during a speech performance it would be difficult for it to be fully experienced without other interventions, as the high RT values in these conditions would worsen the clarity of the speech.

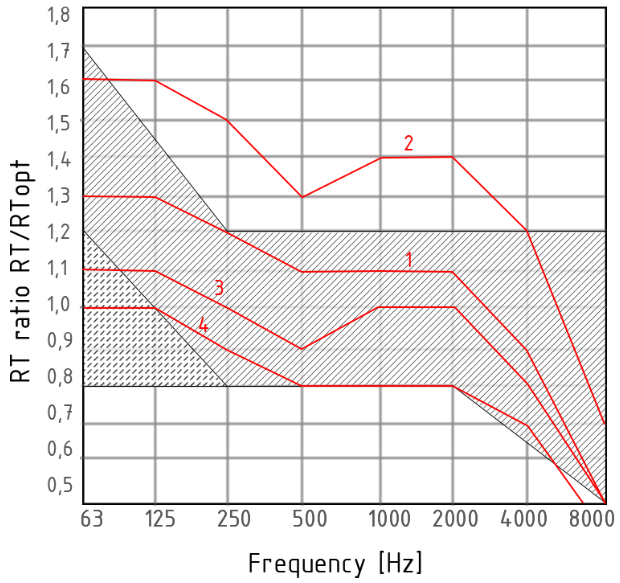

*Figure 60 RT/RTopt ratio for Halle E (**RT**) Simulated RT in occupied Halle E (**RTopt**) Recommended RTm for Halle E (1) Multipurpose rooms for speech and music (2) Speech (3) Solo and chamber music (4) Symphonic music*

The following table presents the RT/RTopt ratio for Kasino am Schwarzenbergplatz at eight octave-band frequencies, where RT represents the simulated mean RT in occupied Kasino am Schwarzenbergplatz and RTopt is the recommended RTm extracted from Figure 55 for the four functions presented in Table 27.

Table 29 RT/RTopt ratio for occupied Kasino am Schwarzenbergplatz (**RT**) Simulated RT in occupied Kasino am Schwarzenbergplatz (**RTopt**) Recommended RTm for Kasino am Schwarzenbergplatz (**1**) Multipurpose rooms for speech and music (**2**) Speech (**3**) Solo and chamber music (**4**) Symphonic music

Kasino am Schwarzen bergplatz	**RT by frequency band [s]**							
	63 **Hz**	125 **Hz**	250 **Hz**	500 **Hz**	1000 **Hz**	2000 **Hz**	4000 **Hz**	8000 **Hz**
Simulated RT [s]	1.58	1.62	1.38	1.46	1.40	1.43	1.28	0.78
RT/RTopt (1)	1.1	1.2	1	1.0	1.0	1.0	0.9	0.6
RT/RTopt (2)	1.3	1.4	1.2	1.2	1.2	1.2	1.1	0.7
RT/RTopt (3)	1	1	0.9	0.9	0.9	0.9	0.8	0.5
RT/RTopt (4)	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.4

The following figure presents the extracted RT/RTopt values from Table 29 and places them in the graph where the acceptable range of RT, previously presented in Figure 54 is shown (Figure 61). Figure 61 shows that the simulated RT in occupied Kasino am Schwarzenbergplatz is inside the RT acceptable range for a multipurpose room, speech and solo and chamber music at all presented frequencies, whereas it is below the RT acceptable range only for symphonic music and at 8000 Hz.

In these conditions, Kasino am Schwarzenbergplatz shows an optimal performance as a multipurpose hall.

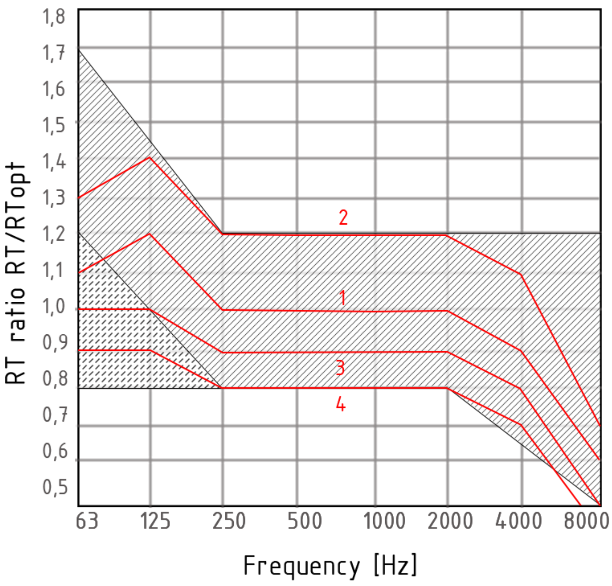

*Figure 61 RT/RTopt ratio for Kasino am Schwarzenbergplatz (**RT**) Simulated RT in occupied Kasino am Schwarzenbergplatz (**RTopt**) Recommended RTm for Kasino am Schwarzenbergplatz (1) Multipurpose rooms for speech and music (2) Speech (3) Solo and chamber music (4) Symphonic music*

The following table presents the RT/RTopt ratio for Kuppelsaal at eight octave-band frequencies, where RT represents the simulated mean RT in occupied Kuppelsaal and RTopt is the recommended RTm extracted from Figure 55 for the four functions presented in Table 27.

Table 30 RT/RTopt ratio for occupied Kuppelsaal (**RT**) Simulated RT in occupied Kuppelsaal (**RTopt**) Recommended RTm for Kuppelsaal (**1**) Multipurpose rooms for speech and music (**2**) Speech (**3**) Solo and chamber music (**4**) Symphonic music

Kuppelsaal	**RT by frequency band [s]**							
	63 **Hz**	125 **Hz**	250 **Hz**	500 **Hz**	1000 **Hz**	2000 **Hz**	4000 **Hz**	8000 **Hz**
Simulated (RT) [s]	1.47	1.43	1.04	1.08	1.01	0.96	1	0.65
RT/RTopt (1)	1.0	1.0	0.8	0.8	0.7	0.7	0.7	0.5
RT/RTopt (2)	1.3	1.2	0.9	0.9	0.9	0.8	0.9	0.6
RT/RTopt (3)	0.9	0.9	0.7	0.7	0.6	0.6	0.6	0.4
RT/RTopt (4)	0.8	0.8	0.6	0.6	0.6	0.5	0.6	0.4

The following figure presents the extracted RT/RTopt values from Table 30 and places them in the graph where the acceptable range of RT, previously presented in Figure 54 is shown (Figure 62).

Figure 62 shows that the simulated RT in occupied Kuppelsaal is inside the RT acceptable range for a multipurpose room at all presented frequencies except at frequencies 1000 Hz and 2000 Hz where the simulated RT is below the acceptable range. For speech the simulated RT is inside the RT acceptable range at all frequencies. For solo and chamber music the simulated RT is inside the RT acceptable range only at frequencies 63 Hz and 125 Hz, and below the acceptable range at all the rest of the presented higher frequencies.

In these conditions, Kuppelsaal shows an optimal performance in events that involve speech, whereas it shows an underperformance as a multi-purpose hall at mid-frequencies 500-4000 Hz.

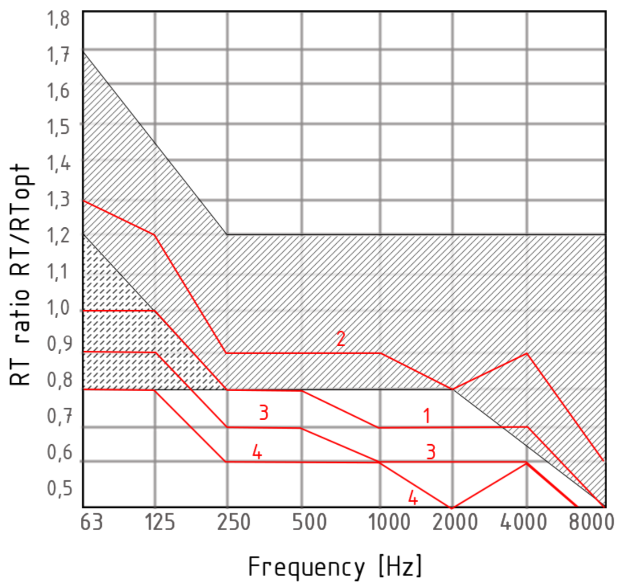

*Figure 62 RT/RTopt ratio for Kuppelsaal (**RT**) Simulated RT in occupied Kuppelsaal (**RTopt**) Recommended RTm for Kuppelsaal (1) Multipurpose rooms for speech and music (2) Speech (3) Solo and chamber music (4) Symphonic music*

The following table presents the RT/RTopt ratio for Rote Bar at eight octave-band frequencies, where RT represents the simulated mean RT in occupied Rote Bar and RTopt is the recommended RTm extracted from Figure 55 for the four functions presented in Table 27.

*Table 31 RT/RTopt ratio for occupied Rote Bar (**RT**) Simulated RT in occupied Rote Bar (**RTopt**) Recommended RTm for Rote Bar (**1**) Multipurpose rooms for speech and music (**2**) Speech (**3**) Solo and chamber music (**4**) Symphonic music*

Rote Bar	**RT by frequency band [s]**							
	63 **Hz**	125 **Hz**	250 **Hz**	500 **Hz**	1000 **Hz**	2000 **Hz**	4000 **Hz**	8000 **Hz**
Simulated (RT) [s]	/	2.34	1.46	1.35	1.16	1.09	0.99	0.69
RT/RTopt (1)	/	2.0	1.2	1.1	1.0	0.9	0.8	0.6
RT/RTopt (2)	/	2.3	1.4	1.3	1.1	1.1	1.0	0.7
RT/RTopt (3)	/	1.7	1.1	1.0	0.8	0.8	0.7	0.5
RT/RTopt (4)	/	1.5	0.9	0.8	0.7	0.7	0.6	0.4

The following figure presents the extracted RT/RTopt values from Table 31 and places them in the graph where the acceptable range of RT, previously presented in Figure 54 is shown (Figure 63).

Figure 63 shows that the simulated RT in occupied Rote Bar is inside the RT acceptable range for a multipurpose room at all presented frequencies except at frequencies below 250 Hz where the simulated RT is above the acceptable range. For speech the simulated RT below 1000 Hz is above the RT acceptable range. For solo and chamber music the simulated RT is above the acceptable range at frequencies below 250 Hz and for symphonic music the simulated RT is inside the RT acceptable range only at the frequency range 125-500 Hz.

In these conditions Rote Bar shows an optimal performance as a multipurpose hall only in frequencies above 250 Hz, and an optimal performance in speech in frequencies above 500 Hz. It shows a remarkably good performance in the function of solo and chamber music.

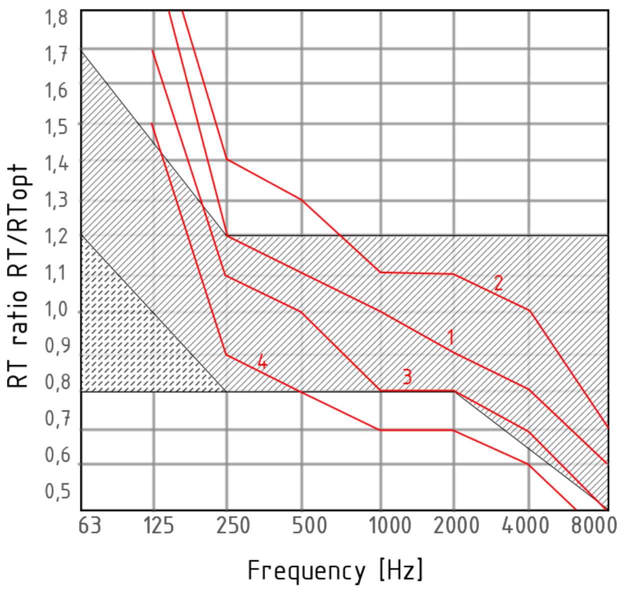

*Figure 63 RT/RTopt ratio for Rote Bar (**RT**) Simulated RT in occupied Rote Bar (**RTopt**) Recommended RTm for Rote Bar (1) Multipurpose rooms for speech and music (2) Speech (3) Solo and chamber music (4) Symphonic music*

- **Comments on SPL**

The results of the SPL show a generally unified sound distribution in the halls. In general, sound decay follows the formula of sound decay over distance. However, the results in all four halls show certain point receivers which are further away from the speaker but have registered higher SPL(A) than point receivers which are closer to the speaker. It is important to point out that in these cases, the difference between the SPL(A) in these points is a matter of 1-3 dB, meaning that it does not disrupt a general unified sound distribution, and this difference is most likely not perceptible to the subjective human hearing.

5 CONCLUSION

This study examined the acoustical performance of multi-purpose halls through an assessment of four case studies. Two approaches were used, namely on-site measurements and simulated models. The results showed that the first run of the simulations was almost in all cases not in agreement with the on-site measurements, which led to a careful re-examination of the first iteration of the simulation models. The calibration process then included change of assigned materials and the properties of the modelled surfaces.

To summarize, the analysis found out that in order to simulate a room as closely as possible to the real state, careful examination of the geometry of the room has to be made. Furthermore, the materials which at first sight seem straightforward and clear may need an examination of the whole construction in case the properties of the last layer of the building component are not enough to describe the acoustical performance of the element. The transmission properties of a surface should not be neglected in cases where both spaces in both sides of the surface are to be considered during the calculation process.

The performance of the halls was described through two main indicators, namely reverberation time and sound pressure levels. The sound pressure levels were used to describe the sound distribution of the sound inside the halls. All four halls showed a generally unified sound distribution and the reverberation time resulted in normal values in all four case studies, being the highest in the hall with the biggest volume. Even though three out of four case studies have big areas of highly reflective surface boundaries, they don't show out of ordinary or unpleasantly high reverberation times; which is a result of added equivalent absorption areas inside the halls, such as the heavily upholstered chairs and heavy velour drapes. Therefore a balance of reflective and absorbent areas inside the hall is crucial.

The simulations with added audience result in lower reverberation times, as expected, therefore for performances based on speech they performed better when the auditorium was occupied.

The simulation models have shown an overall useful tool in interpreting the performance of the halls. Further research questions arise in the direction of tackling the resonant frequencies of the room and finding out how and where they exactly affect the performance of the reverberation time and sound pressure levels.

6 INDEX

6.1 List of Abbreviations

RT	Reverberation time
α	Absorption coefficient
SPL	Sound pressure level
SPL(A)	Sound pressure level (A weighted)
RT_m	Mid-frequency reverberation time at 500 Hz
RTopt	Recommended RT at 500 Hz

6.2 List of Figures

6.3 List of Tables

6.4 List of Equations

7 LITERATURE

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8 APPENDIX

A. Figures

- **Measured background noise**

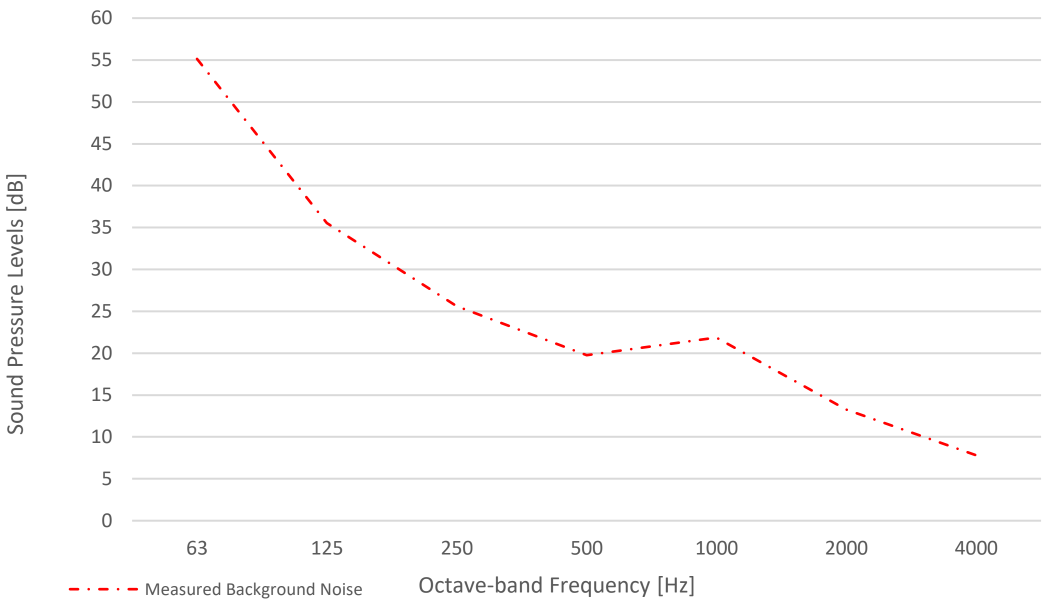

Figure 64 Measured background noise in Kasino am Schwarzenbergplatz

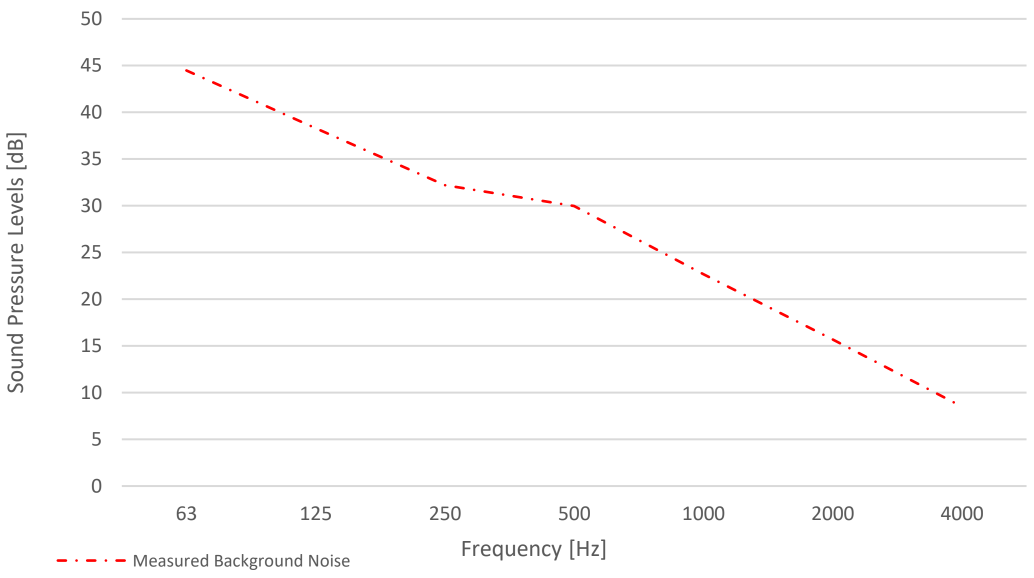

Figure 65 Measured background noise in Kuppelsaal

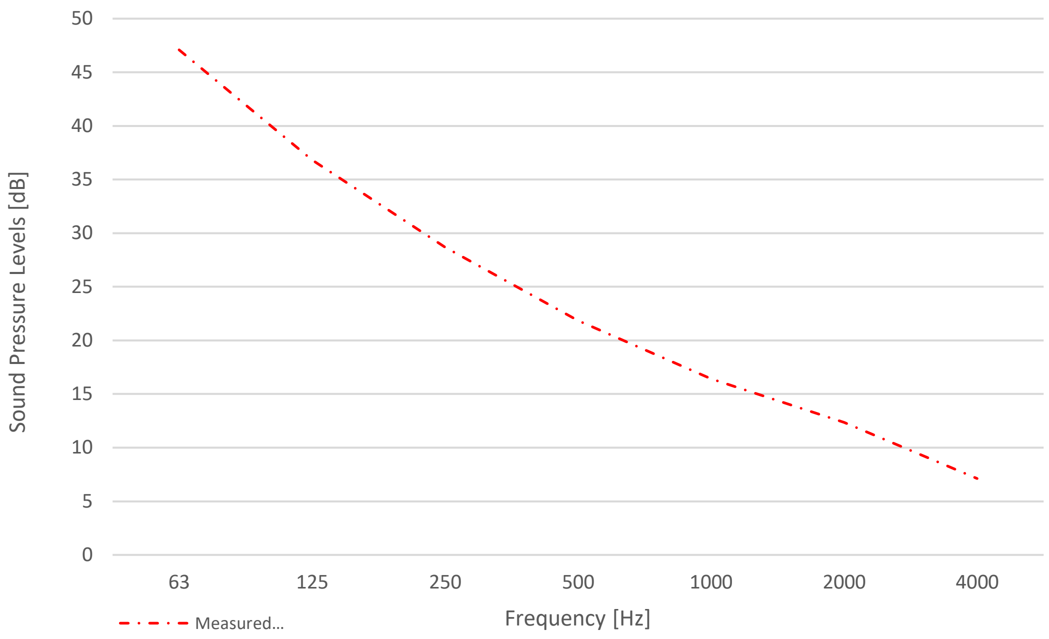

Figure 66 Measured background noise in Rote Bar

B. Tables

The following tables present the calculation parameters of the iterations in Odeon as well as additional energy parameters that were not presented in the paper.

- **Halle E**

Calculation parameters

Number of rays used	72016 (rays lost 9 = 0.0 %)
Impulse response length	2000 ms
Max. reflection order	2000
Impulse response resolution	3.0000 ms
Transition order	2
Number of early rays	9002
Number of early scatter rays	100
Angular absorption	Soft materials only
Screen diffraction	On
Surface scattering	Actual
Oblique Lambert	On
Reflection based scatter	Enabled
Key diffraction frequency	707 Hz
Interior margin	0.10 m
Uniform scatter for coefficients	0 >,5 0

(Ray flights processed 12786211) (Mean free path 3.91 m)

Energy parameters

EDT (s)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	1.63	1.7	1.66	1.56	1.62	1.66	1.42	0.78
Maximum	1.97	2	1.98	1.91	2	2.09	1.86	1.29
Average	1.79	1.85	1.82	1.74	1.81	1.86	1.61	0.98
Std.dev.	0.11	0.11	0.11	0.12	0.12	0.13	0.13	0.14

T(15) (s)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	1.75	1.79	1.74	1.64	1.75	1.79	1.5	0.86
Maximum	2.06	2.03	1.85	1.74	1.84	1.88	1.59	0.95
Average	1.93	1.94	1.81	1.69	1.8	1.84	1.56	0.9
Std.dev.	0.09	0.08	0.04	0.03	0.03	0.03	0.03	0.02

T(20) (s)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	1.92	1.93	1.8	1.69	1.79	1.85	1.51	0.86
Maximum	2.2	2.17	1.91	1.77	1.86	1.9	1.58	0.93
Average	2.09	2.09	1.87	1.73	1.83	1.87	1.56	0.9
Std.dev.	0.07	0.07	0.03	0.02	0.02	0.02	0.02	0.02

Curvature(C) (%)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	4.4	4.5	3.1	1	0	0.1	0.5	-0.5
Maximum	14.3	13	7.2	5.1	6.7	5.7	4.6	1.9
Average	8.8	9.5	4.9	3.4	2.9	2.2	1.5	0.9
Std.dev.	2.6	2.5	1.1	1.2	1.7	1.5	1	0.8

Ts (ms)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	98	104	101	90	96	102	86	47
Maximum	158	156	151	140	146	153	129	66
Average	128	130	125	112	117	122	102	53
Std.dev.	19	17	15	14	14	15	13	6

SPL (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	61.3	75.7	85.7	79.1	74.6	70.2	63.3	40.4
Maximum	62.7	77.3	87.1	80.6	75.9	71.5	64.7	42.3
Average	61.8	76.4	86.4	80	75.3	71	64.2	41.3
Std.dev.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6

D(50)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.21	0.22	0.25	0.29	0.28	0.28	0.33	0.54
Maximum	0.48	0.45	0.48	0.53	0.51	0.48	0.52	0.7
Average	0.34	0.34	0.36	0.41	0.4	0.39	0.44	0.63
Std.dev.	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.05

C(7) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-9.4	-9.2	-9.4	-9.5	-9.7	-9.8	-9.4	-7.3
Maximum	-6.4	-6.3	-5.8	-5.1	-4.9	-5.4	-4.6	-0.7
Average	-7.6	-7.1	-7.1	-6.5	-6.6	-6.8	-6.1	-3.4
Std.dev.	0.8	0.7	0.9	1.2	1.3	1.3	1.4	1.8

C(50) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-5.8	-5.4	-4.8	-3.9	-4	-4.1	-3	0.8
Maximum	-0.4	-0.8	-0.3	0.5	0.2	-0.3	0.4	3.8
Average	-3.1	-3	-2.6	-1.6	-1.8	-2	-1.1	2.4
Std.dev.	1.7	1.5	1.3	1.3	1.3	1.3	1.2	1

C(80) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-3.8	-3.6	-3.2	-2.5	-2.6	-2.7	-1.6	2.4
Maximum	1.3	1.1	1.4	2	1.9	1.6	2.4	6.1
Average	-1.1	-1.1	-0.8	0	-0.1	-0.3	0.6	4.5

Std.dev.	1.6	1.5	1.3	1.3	1.3	1.3	1.3	1.2

U(50) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-5.8	-5.4	-4.8	-3.9	-4	-4.1	-3	0.8
Maximum	-0.4	-0.8	-0.3	0.5	0.2	-0.3	0.4	3.8
Average	-3.1	-3	-2.6	-1.6	-1.8	-2	-1.1	2.4
Std.dev.	1.7	1.5	1.3	1.3	1.3	1.3	1.2	1

U(80) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-3.8	-3.6	-3.2	-2.5	-2.6	-2.7	-1.6	2.4
Maximum	1.3	1.1	1.4	2	1.9	1.6	2.4	6.1
Average	-1.1	-1.1	-0.8	0	-0.1	-0.3	0.6	4.5
Std.dev.	1.6	1.5	1.3	1.3	1.3	1.3	1.3	1.2

LF(80)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.1	0.091	0.1	0.111	0.109	0.118	0.121	0.095
Maximum	0.18	0.18	0.197	0.21	0.204	0.203	0.201	0.18
Average	0.144	0.142	0.156	0.162	0.162	0.168	0.17	0.151
Std.dev.	0.023	0.027	0.025	0.022	0.021	0.02	0.019	0.02

LFC(80)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.181	0.156	0.161	0.17	0.173	0.186	0.187	0.147
Maximum	0.292	0.292	0.315	0.344	0.346	0.343	0.34	0.312
Average	0.248	0.243	0.262	0.276	0.279	0.288	0.29	0.264
Std.dev.	0.032	0.04	0.04	0.04	0.039	0.037	0.036	0.041

Diffusivity(ss) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	2.4	2.3	2.4	2.3	2.3	2.4	2.3	1.6
Maximum	3.4	3.3	4	5	5.6	6.7	7.3	6.8
Average	2.9	2.8	3	3	3.1	3.6	3.7	2.9
Std.dev.	0.3	0.3	0.4	0.9	1.1	1.4	1.6	1.7

Echo(Dietsch)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.58	0.58	0.59	0.56	0.56	0.53	0.51	0.47
Maximum	0.81	0.85	0.87	0.9	0.83	0.76	0.75	0.7
Average	0.65	0.66	0.66	0.65	0.63	0.62	0.61	0.57
Std.dev.	0.05	0.07	0.07	0.09	0.07	0.06	0.07	0.06

SPL(A),	Minimum	81.3	dB
SPL(A),	Maximum	82.7	dB
SPL(A),	Average	82.1	dB
SPL(A),	Std.dev.	0.4	dB
SPL(Lin),	Minimum	87.2	dB
SPL(Lin),	Maximum	88.7	dB
SPL(Lin),	Average	88	dB
SPL(Lin),	Std.dev.	0.4	dB
SPL(C),	Minimum	87.2	dB
SPL(C),	Maximum	88.7	dB
SPL(C),	Average	88	dB
SPL(C),	Std.dev.	0.4	dB
STI,	Minimum	0.44	
STI,	Maximum	0.55	
STI,	Average	0.51	
STI,	Std.dev.	0.03	
STI(Female),	Minimum	0.43	
STI(Female),	Maximum	0.54	
STI(Female),	Average	0.49	
STI(Female),	Std.dev.	0.03	
STI(Male),	Minimum	0.42	
STI(Male),	Maximum	0.53	
STI(Male),	Average	0.49	
STI(Male),	Std.dev.	0.03	
RASTI,	Minimum	0.41	
RASTI,	Maximum	0.53	
RASTI,	Average	0.48	
RASTI,	Std.dev.	0.04	
STI(expected),	Minimum	0.47	
STI(expected),	Maximum	0.48	
STI(expected),	Average	0.47	
STI(expected),	Std.dev.	0	
T(30_Avrerage),	Minimum	1.8	s
T(30_Avrerage),	Maximum	1.9	s
T(30_Avrerage),	Average	1.8	s
T(30_Avrerage),	Std.dev.	0	s

LF(80_Avrerage),	Minimum	0.103	
LF(80_Avrerage),	Maximum	0.198	
LF(80_Avrerage),	Average	0.155	
LF(80_Avrerage),	Std.dev.	0.022	
Lj(Avrerage),	Minimum	-0.7	dB
Lj(Avrerage),	Maximum	-0.3	dB
Lj(Avrerage),	Average	-0.5	dB
Lj(Avrerage),	Std.dev.	0.1	dB
BR(SPL),	Minimum	3.4	dB
BR(SPL),	Maximum	4.1	dB
BR(SPL),	Average	3.8	dB
BR(SPL),	Std.dev.	0.3	dB
SIL,	Minimum	71.8	dB
SIL,	Maximum	73.2	dB
SIL,	Average	72.6	dB
SIL,	Std.dev.	0.4	dB
AI,	Minimum	1	
AI,	Maximum	1	
AI,	Average	1	
AI,	Std.dev.	0	
Alcons(STI),	Minimum	9.31	%
Alcons(STI),	Maximum	16.34	%
Alcons(STI),	Average	12.02	%
Alcons(STI),	Std.dev.	2.16	%
Density(reflections),	Minimum	963.96	/ms
Density(reflections),	Maximum	1221.76	/ms
Density(reflections),	Average	1077.07	/ms
Density(reflections),	Std.dev.	85.31	/ms

- **Kasino am Schwarzenbergplatz**

Calculation parameters

Number of rays used	54528 (rays lost 15 = 0.0 %)
Impulse response length	2000 ms
Max. reflection order	2000
Impulse response resolution	3.0000 ms
Transition order	2
Number of early rays	6816
Number of early scatter rays	100
Angular absorption	Soft materials only

Screen diffraction	On
Surface scattering	Actual
Oblique Lambert	On
Reflection based scatter	Enabled
Key diffraction frequency	707 Hz
Interior margin	0.10 m
Uniform scatter for coefficients	0 >,5 0

(Ray flights processed 8864546) (Mean free path 4.25 m)

Energy parameters

EDT (s)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	1.36	1.34	1.03	0.92	0.82	0.85	0.79	0.49
Maximum	1.59	1.56	1.29	1.22	1.12	1.13	1.05	0.73
Average	1.47	1.45	1.17	1.09	0.99	1.01	0.94	0.64
Std.dev.	0.07	0.07	0.08	0.09	0.1	0.09	0.08	0.07

T(15) (s)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	1.5	1.48	1.19	1.09	0.98	0.99	0.92	0.63
Maximum	1.57	1.53	1.27	1.22	1.18	1.21	1.06	0.71
Average	1.53	1.5	1.23	1.15	1.09	1.1	0.99	0.67
Std.dev.	0.02	0.01	0.02	0.04	0.06	0.06	0.04	0.02

T(20) (s)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	1.51	1.49	1.21	1.11	1.02	1.03	0.93	0.64
Maximum	1.58	1.52	1.31	1.27	1.28	1.31	1.09	0.7
Average	1.54	1.51	1.24	1.18	1.14	1.16	1.02	0.67
Std.dev.	0.01	0.01	0.03	0.04	0.07	0.07	0.04	0.02

Curvature(C) (%)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-3.5	-1.2	0.9	2.7	3.6	1.9	2.9	-3.9
Maximum	1.9	1.5	5.9	9.1	20.5	31.6	7.8	3.9
Average	0.1	0.3	3.8	7	12.5	12.5	5.2	1.4
Std.dev.	1.2	0.8	1.1	1.6	3.5	5.5	1.5	2

Ts (ms)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	79	79	62	58	53	56	51	33
Maximum	104	101	79	74	66	68	65	45
Average	90	89	71	66	59	62	57	36
Std.dev.	6	5	4	4	4	4	4	3

D(50)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.4	0.41	0.49	0.51	0.55	0.53	0.54	0.66
Maximum	0.56	0.56	0.63	0.65	0.68	0.65	0.68	0.8
Average	0.48	0.48	0.55	0.57	0.6	0.58	0.6	0.73
Std.dev.	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03

C(7) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-8.6	-9.7	-9.2	-8.9	-8.1	-7.8	-7.9	-6.7
Maximum	-4.2	-3.8	-2.4	-2	-1.6	-2.3	-1.6	0.8
Average	-6.2	-5.9	-4.9	-4.5	-4	-4.3	-4	-2.2
Std.dev.	1.3	1.5	1.6	1.6	1.5	1.4	1.5	1.7

C(50) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-1.8	-1.6	-0.2	0.2	0.9	0.5	0.7	2.9
Maximum	1.1	1.1	2.3	2.6	3.3	2.8	3.4	6
Average	-0.4	-0.3	0.9	1.2	1.8	1.4	1.8	4.3
Std.dev.	0.7	0.7	0.7	0.8	0.7	0.7	0.8	0.8

C(80) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.8	1	2.5	2.7	3.3	3.1	3.5	6.2
Maximum	3.3	3.3	4.8	5.3	5.9	5.4	6	9.3
Average	2.2	2.3	3.6	4	4.7	4.4	4.9	8.1
Std.dev.	0.6	0.6	0.6	0.7	0.7	0.6	0.6	0.7

U(50) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-1.8	-1.6	-0.2	0.2	0.9	0.5	0.7	2.9
Maximum	1.1	1.1	2.3	2.6	3.3	2.8	3.4	6
Average	-0.4	-0.3	0.9	1.2	1.8	1.4	1.8	4.3
Std.dev.	0.7	0.7	0.7	0.8	0.7	0.7	0.8	0.8

U(80) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.8	1	2.5	2.7	3.3	3.1	3.5	6.2
Maximum	3.3	3.3	4.8	5.3	5.9	5.4	6	9.3
Average	2.2	2.3	3.6	4	4.7	4.4	4.9	8.1
Std.dev.	0.6	0.6	0.6	0.7	0.7	0.6	0.6	0.7

LF(80)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.104	0.093	0.08	0.075	0.067	0.075	0.077	0.059
Maximum	0.346	0.342	0.332	0.334	0.328	0.328	0.33	0.333
Average	0.188	0.174	0.154	0.142	0.129	0.134	0.137	0.122

Std.dev.	0.055	0.057	0.059	0.061	0.061	0.058	0.058	0.062

LFC(80)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.166	0.146	0.13	0.123	0.115	0.128	0.13	0.104
Maximum	0.424	0.417	0.401	0.396	0.383	0.387	0.389	0.383
Average	0.281	0.262	0.237	0.222	0.205	0.213	0.219	0.195
Std.dev.	0.063	0.066	0.066	0.066	0.065	0.061	0.061	0.065

Diffusivity(ss) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	3.2	2.6	2.2	2	1.8	1.9	1.9	1.3
Maximum	5.2	4.4	4.5	4.7	4.6	4.7	4.7	4.3
Average	4.2	3.4	3	3	2.7	2.8	2.8	2.3
Std.dev.	0.6	0.5	0.6	0.8	0.7	0.7	0.7	0.7

Echo(Dietsch)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.43	0.43	0.42	0.41	0.41	0.43	0.42	0.38
Maximum	0.54	0.57	0.58	0.58	0.58	0.59	0.58	0.55
Average	0.49	0.49	0.49	0.49	0.49	0.5	0.49	0.46
Std.dev.	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.05

SPL(A),	Minimum	89.6	dB
SPL(A),	Maximum	92.7	dB
SPL(A),	Average	91.2	dB
SPL(A),	Std.dev.	0.8	dB
SPL(Lin),	Minimum	95.1	dB
SPL(Lin),	Maximum	97.8	dB
SPL(Lin),	Average	96.5	dB
SPL(Lin),	Std.dev.	0.7	dB
SPL(C),	Minimum	95	dB
SPL(C),	Maximum	97.8	dB
SPL(C),	Average	96.4	dB
SPL(C),	Std.dev.	0.7	dB
STI,	Minimum	0.58	
STI,	Maximum	0.64	
STI,	Average	0.6	
STI,	Std.dev.	0.02	
STI(Female),	Minimum	0.48	

STI(Female),	Maximum	0.53	
STI(Female),	Average	0.5	
STI(Female),	Std.dev.	0.01	
STI(Male),	Minimum	0.49	
STI(Male),	Maximum	0.54	
STI(Male),	Average	0.51	
STI(Male),	Std.dev.	0.01	
RASTI,	Minimum	0.57	
RASTI,	Maximum	0.63	
RASTI,	Average	0.59	
RASTI,	Std.dev.	0.02	
STI(expected),	Minimum	0.54	
STI(expected),	Maximum	0.57	
STI(expected),	Average	0.55	
STI(expected),	Std.dev.	0.01	
T(30_Avrerage),	Minimum	1.2	s
T(30_Avrerage),	Maximum	1.4	s
T(30_Avrerage),	Average	1.3	s
T(30_Avrerage),	Std.dev.	0.1	s
LF(80_Avrerage),	Minimum	0.079	
LF(80_Avrerage),	Maximum	0.334	
LF(80_Avrerage),	Average	0.15	
LF(80_Avrerage),	Std.dev.	0.059	
Lj(Avrerage),	Minimum	-1.5	dB
Lj(Avrerage),	Maximum	-0.9	dB
Lj(Avrerage),	Average	-1.1	dB
Lj(Avrerage),	Std.dev.	0.1	dB
BR(SPL),	Minimum	4.1	dB
BR(SPL),	Maximum	5.2	dB
BR(SPL),	Average	4.6	dB
BR(SPL),	Std.dev.	0.3	dB
SIL,	Minimum	82.2	dB
SIL,	Maximum	85.5	dB
SIL,	Average	83.9	dB
SIL,	Std.dev.	0.8	dB
AI,	Minimum	1	
AI,	Maximum	1	

AI,	Average	1	
AI,	Std.dev.	0	
Alcons(STI),	Minimum	6.17	%
Alcons(STI),	Maximum	8.28	%
Alcons(STI),	Average	7.43	%
Alcons(STI),	Std.dev.	0.64	%
Density(reflections),	Minimum	863.49	/ms
Density(reflections),	Maximum	1135.44	/ms
Density(reflections),	Average	1064.14	/ms
Density(reflections),	Std.dev.	64.72	/ms

- **Kuppelsaal**

Calculation parameters

Number of rays used	66880 (rays lost 30 = 0.0 %)
Impulse response length	2000 ms
Max. reflection order	2000
Impulse response resolution	3.0000 ms
Transition order	2
Number of early rays	8360
Number of early scatter rays	100
Angular absorption	Soft materials only
Screen diffraction	On
Surface scattering	Actual
Oblique Lambert	On
Reflection based scatter	Enabled
Key diffraction frequency	707 Hz
Interior margin	0.10 m
Uniform scatter for coefficients	0 >,5 0

(Ray flights processed 9057681) (Mean free path 5.11 m)

Energy parameters

EDT (s)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	1.32	1.24	0.62	0.72	0.58	0.54	0.55	0.21
Maximum	1.75	1.66	1.27	1.33	1.23	1.18	1.18	0.75
Average	1.66	1.57	1.13	1.19	1.08	1.02	1.03	0.61
Std.dev.	0.1	0.1	0.16	0.15	0.16	0.16	0.16	0.13

T(15) (s)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	1.65	1.56	1.12	1.19	1.08	1.02	1.03	0.63
Maximum	1.69	1.6	1.2	1.26	1.17	1.12	1.12	0.74
Average	1.67	1.58	1.16	1.22	1.12	1.07	1.08	0.7
Std.dev.	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.03

T(20) (s)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	1.65	1.57	1.13	1.2	1.09	1.03	1.05	0.64
Maximum	1.7	1.6	1.19	1.24	1.15	1.1	1.11	0.72
Average	1.68	1.58	1.16	1.22	1.12	1.07	1.08	0.7
Std.dev.	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02

Curvature(C) (%)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-1	-0.9	-1.9	-1.7	-2	-1.8	-1.4	-2
Maximum	1.4	0.5	0.9	0.9	1.4	1.6	1.9	3
Average	0.2	-0.2	-0.2	-0.3	-0.3	-0.3	-0.1	-0.7
Std.dev.	0.6	0.4	0.7	0.6	0.8	0.8	0.8	1.2

Ts (ms)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	35	32	20	22	20	18	18	9
Maximum	135	125	90	96	88	83	85	54
Average	103	96	66	71	64	61	62	37
Std.dev.	27	24	19	19	18	18	18	13

D(50)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.26	0.29	0.39	0.37	0.39	0.42	0.41	0.58
Maximum	0.82	0.83	0.89	0.88	0.89	0.9	0.89	0.95
Average	0.45	0.48	0.58	0.56	0.59	0.6	0.59	0.74
Std.dev.	0.15	0.14	0.13	0.13	0.13	0.13	0.13	0.1

C(7) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-13.8	-12.9	-11.8	-12.3	-12.1	-11.9	-12.3	-10.4
Maximum	4.5	4.6	5.7	5.2	5.4	5.7	5.6	7.7
Average	-6.6	-6.4	-5	-5.5	-5.2	-5	-5.2	-2.9
Std.dev.	5.1	4.9	4.9	5	5	5	5.1	5.1

C(50) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-4.5	-3.9	-1.9	-2.3	-1.9	-1.5	-1.7	1.3
Maximum	6.7	7	9	8.5	9	9.3	9.2	12.6
Average	-0.9	-0.4	1.6	1.3	1.8	2.1	1.9	5
Std.dev.	2.8	2.7	2.7	2.7	2.7	2.7	2.7	2.9

C(80) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000

Minimum	-1.5	-0.8	1.5	1	1.6	2.1	1.9	5.5
Maximum	7.8	8.1	10.2	9.7	10.4	10.8	10.8	15.2
Average	1.3	1.8	4	3.6	4.2	4.6	4.4	8.3
Std.dev.	2.4	2.2	2.2	2.2	2.2	2.2	2.3	2.5

U(50) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-4.5	-3.9	-1.9	-2.3	-1.9	-1.5	-1.7	1.3
Maximum	6.7	7	9	8.5	9	9.3	9.2	12.6
Average	-0.9	-0.4	1.6	1.3	1.8	2.1	1.9	5
Std.dev.	2.8	2.7	2.7	2.7	2.7	2.7	2.7	2.9

U(80) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-1.5	-0.8	1.5	1	1.6	2.1	1.9	5.5
Maximum	7.8	8.1	10.2	9.7	10.4	10.8	10.8	15.2
Average	1.3	1.8	4	3.6	4.2	4.6	4.4	8.3
Std.dev.	2.4	2.2	2.2	2.2	2.2	2.2	2.3	2.5

LF(80)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.054	0.054	0.052	0.055	0.054	0.053	0.054	0.042
Maximum	0.255	0.256	0.265	0.284	0.289	0.291	0.292	0.279
Average	0.164	0.169	0.172	0.185	0.187	0.189	0.192	0.174
Std.dev.	0.065	0.068	0.071	0.077	0.077	0.077	0.078	0.076

LFC(80)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.081	0.081	0.079	0.084	0.083	0.08	0.082	0.064
Maximum	0.402	0.4	0.41	0.433	0.432	0.428	0.432	0.403
Average	0.265	0.27	0.268	0.286	0.287	0.29	0.295	0.268
Std.dev.	0.099	0.1	0.104	0.111	0.112	0.113	0.113	0.113

Diffusivity(ss) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	1.8	1.8	1.5	1.6	1.4	1.4	1.3	0.9
Maximum	6.7	6.7	7	7.9	7.9	8.2	9.1	7.7
Average	5	5	4.4	4.8	4.7	4.7	4.9	3.7
Std.dev.	1.5	1.5	1.6	1.8	1.8	1.9	2	1.8

Echo(Dietsch)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.43	0.43	0.4	0.4	0.39	0.38	0.39	0.36
Maximum	0.59	0.61	0.58	0.55	0.55	0.54	0.54	0.51
Average	0.5	0.5	0.48	0.48	0.47	0.47	0.47	0.43

Std.dev.	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

SPL(A),	Minimum	86.1	dB
SPL(A),	Maximum	95.5	dB
SPL(A),	Average	89.1	dB
SPL(A),	Std.dev.	2.4	dB
SPL(Lin),	Minimum	90.9	dB
SPL(Lin),	Maximum	100.2	dB
SPL(Lin),	Average	94	dB
SPL(Lin),	Std.dev.	2.4	dB
SPL(C),	Minimum	90.8	dB
SPL(C),	Maximum	100.1	dB
SPL(C),	Average	93.9	dB
SPL(C),	Std.dev.	2.4	dB
STI,	Minimum	0.52	
STI,	Maximum	0.8	
STI,	Average	0.62	
STI,	Std.dev.	0.07	
STI(Female),	Minimum	0.44	
STI(Female),	Maximum	0.63	
STI(Female),	Average	0.53	
STI(Female),	Std.dev.	0.05	
STI(Male),	Minimum	0.45	
STI(Male),	Maximum	0.64	
STI(Male),	Average	0.53	
STI(Male),	Std.dev.	0.05	
RASTI,	Minimum	0.51	
RASTI,	Maximum	0.79	
RASTI,	Average	0.61	
RASTI,	Std.dev.	0.07	
STI(expected),	Minimum	0.57	
STI(expected),	Maximum	0.57	
STI(expected),	Average	0.57	
STI(expected),	Std.dev.	0	
T(30_Avrerage),	Minimum	1.2	s
T(30_Avrerage),	Maximum	1.2	s
T(30_Avrerage),	Average	1.2	s

T(30_Avrerage),	Std.dev.	0	s
LF(80_Avrerage),	Minimum	0.054	
LF(80_Avrerage),	Maximum	0.273	
LF(80_Avrerage),	Average	0.178	
LF(80_Avrerage),	Std.dev.	0.073	
Lj(Avrerage),	Minimum	-2.1	dB
Lj(Avrerage),	Maximum	-0.5	dB
Lj(Avrerage),	Average	-0.9	dB
Lj(Avrerage),	Std.dev.	0.4	dB
BR(SPL),	Minimum	4.8	dB
BR(SPL),	Maximum	5.5	dB
BR(SPL),	Average	5.1	dB
BR(SPL),	Std.dev.	0.2	dB
SIL,	Minimum	78.8	dB
SIL,	Maximum	88.1	dB
SIL,	Average	81.7	dB
SIL,	Std.dev.	2.4	dB
AI,	Minimum	1	
AI,	Maximum	1	
AI,	Average	1	
AI,	Std.dev.	0	
Alcons(STI),	Minimum	2.77	%
Alcons(STI),	Maximum	11.05	%
Alcons(STI),	Average	7.21	%
Alcons(STI),	Std.dev.	2.11	%
Density(reflections),	Minimum	2109.56	/ms
Density(reflections),	Maximum	2441.12	/ms
Density(reflections),	Average	2295.04	/ms
Density(reflections),	Std.dev.	95.73	/ms

- **Rote Bar**

Calculation parameters

Number of rays used	165728 (rays lost 16466 = 9.9 %)
Impulse response length	2000 ms
Max. reflection order	2000
Impulse response resolution	3.0000 ms
Transition order	2

Number of early rays	20716
Number of early scatter rays	100
Angular absorption	Soft materials only
Screen diffraction	On
Surface scattering	Actual
Oblique Lambert	On
Reflection based scatter	Enabled
Key diffraction frequency	707 Hz
Interior margin	0.10 m
Uniform scatter for coefficients	0 >,5 0

(Ray flights processed 58166636) (Mean free path 1.61 m)

Energy parameters:

EDT (s)								
Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	2.38	2.24	1.38	1.26	1.06	0.93	0.82	0.51
Maximum	2.52	2.38	1.56	1.45	1.28	1.28	1.19	0.84
Average	2.47	2.33	1.47	1.36	1.17	1.11	1.02	0.68
Std.dev.	0.04	0.04	0.05	0.06	0.07	0.11	0.12	0.11

T(15) (s)								
Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	2.48	2.34	1.48	1.36	1.14	1.08	1	0.69
Maximum	2.51	2.37	1.5	1.39	1.19	1.17	1.09	0.79
Average	2.49	2.35	1.49	1.37	1.17	1.11	1.03	0.72
Std.dev.	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.03

T(20) (s)								
Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	2.49	2.35	1.48	1.35	1.15	1.09	1.01	0.68
Maximum	2.51	2.38	1.51	1.38	1.19	1.15	1.06	0.75
Average	2.5	2.36	1.49	1.37	1.17	1.11	1.03	0.71
Std.dev.	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02

Curvature(C) (%)								
Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-0.5	-0.7	-0.6	-1.4	-2.1	-2.5	-2.2	-3.7
Maximum	0	0.1	1.5	2.2	2.5	0.9	0.8	2.6
Average	-0.2	-0.2	0.2	-0.2	-0.7	-0.6	-0.3	-0.5
Std.dev.	0.2	0.3	0.7	0.9	1.1	1	0.9	1.7

Ts (ms)								
Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	142	132	69	59	42	32	27	14
Maximum	186	176	110	101	82	74	66	43
Average	171	160	93	84	67	57	49	30

Std.dev.	13	13	13	13	13	14	13	9

D(50)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.22	0.23	0.35	0.38	0.44	0.51	0.55	0.69
Maximum	0.4	0.42	0.61	0.65	0.73	0.79	0.81	0.89
Average	0.29	0.3	0.46	0.5	0.57	0.62	0.66	0.79
Std.dev.	0.05	0.06	0.08	0.08	0.09	0.09	0.09	0.07

C(7) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-16.6	-16.8	-12.9	-12.4	-10.6	-9	-8	-6.1
Maximum	-7	-6.6	-2.3	-1.2	1.7	4.2	4.8	7
Average	-11.5	-11.3	-7.6	-6.9	-4.9	-3	-2.1	-0.2
Std.dev.	3.1	3.2	3.3	3.5	3.8	4.2	4.2	4.3

C(50) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-5.6	-5.3	-2.7	-2.2	-1	0.1	0.9	3.5
Maximum	-1.8	-1.4	2	2.7	4.4	5.6	6.3	9.2
Average	-4	-3.7	-0.7	-0.1	1.3	2.3	3.1	5.8
Std.dev.	1.1	1.1	1.3	1.4	1.6	1.8	1.8	1.8

C(80) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-2.9	-2.7	0	0.5	1.7	2.8	3.5	6.7
Maximum	0	0.4	3.8	4.5	6.2	7.4	8.2	11.7
Average	-1.8	-1.5	1.6	2.2	3.6	4.6	5.5	8.8
Std.dev.	0.9	0.9	1.1	1.1	1.3	1.5	1.5	1.6

U(50) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-5.6	-5.3	-2.7	-2.2	-1	0.1	0.9	3.5
Maximum	-1.8	-1.4	2	2.7	4.4	5.6	6.3	9.2
Average	-4	-3.7	-0.7	-0.1	1.3	2.3	3.1	5.8
Std.dev.	1.1	1.1	1.3	1.4	1.6	1.8	1.8	1.8

U(80) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	-2.9	-2.7	0	0.5	1.7	2.8	3.5	6.7
Maximum	0	0.4	3.8	4.5	6.2	7.4	8.2	11.7
Average	-1.8	-1.5	1.6	2.2	3.6	4.6	5.5	8.8
Std.dev.	0.9	0.9	1.1	1.1	1.3	1.5	1.5	1.6

LF(80)

Band (Hz)	63	125	250	500	1000	2000	4000	8000

Minimum	0.117	0.115	0.085	0.082	0.066	0.04	0.038	0.032
Maximum	0.276	0.279	0.257	0.265	0.263	0.268	0.256	0.236
Average	0.209	0.21	0.187	0.184	0.172	0.166	0.161	0.141
Std.dev.	0.048	0.049	0.054	0.058	0.064	0.073	0.071	0.066

LFC(80)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.203	0.2	0.149	0.141	0.109	0.063	0.059	0.05
Maximum	0.408	0.411	0.37	0.364	0.346	0.371	0.378	0.338
Average	0.336	0.336	0.298	0.292	0.269	0.25	0.241	0.213
Std.dev.	0.062	0.063	0.073	0.077	0.088	0.102	0.1	0.095

Diffusivity(ss) (dB)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	5.1	4.8	3.3	3.1	2.6	2.1	1.9	1.3
Maximum	8.6	8.8	7.7	7.9	7.6	8.9	10.7	11.6
Average	6.9	6.9	5.7	5.6	5.1	5	4.9	4.2
Std.dev.	1.2	1.3	1.4	1.5	1.7	2.2	2.6	3

Echo(Dietsch)

Band (Hz)	63	125	250	500	1000	2000	4000	8000
Minimum	0.46	0.46	0.43	0.43	0.43	0.41	0.4	0.37
Maximum	0.52	0.52	0.53	0.54	0.55	0.57	0.56	0.53
Average	0.49	0.48	0.47	0.47	0.47	0.48	0.48	0.44
Std.dev.	0.02	0.02	0.03	0.03	0.04	0.05	0.05	0.05

SPL(A),	Minimum	89	dB
SPL(A),	Maximum	92.7	dB
SPL(A),	Average	90.7	dB
SPL(A),	Std.dev.	1	dB
SPL(Lin),	Minimum	94.5	dB
SPL(Lin),	Maximum	97.9	dB
SPL(Lin),	Average	96.1	dB
SPL(Lin),	Std.dev.	0.9	dB
SPL(C),	Minimum	94.5	dB
SPL(C),	Maximum	97.8	dB
SPL(C),	Average	96.1	dB
SPL(C),	Std.dev.	0.9	dB
STI,	Minimum	0.54	

STI,	Maximum	0.67	
STI,	Average	0.59	
STI,	Std.dev.	0.04	
STI(Female),	Minimum	0.48	
STI(Female),	Maximum	0.61	
STI(Female),	Average	0.54	
STI(Female),	Std.dev.	0.04	
STI(Male),	Minimum	0.48	
STI(Male),	Maximum	0.61	
STI(Male),	Average	0.54	
STI(Male),	Std.dev.	0.04	
RASTI,	Minimum	0.53	
RASTI,	Maximum	0.67	
RASTI,	Average	0.59	
RASTI,	Std.dev.	0.05	
STI(expected),	Minimum	0.54	
STI(expected),	Maximum	0.55	
STI(expected),	Average	0.55	
STI(expected),	Std.dev.	0	
T(30_Avrerage),	Minimum	1.3 s	
T(30_Avrerage),	Maximum	1.3 s	
T(30_Avrerage),	Average	1.3 s	
T(30_Avrerage),	Std.dev.	0 s	
LF(80_Avrerage),	Minimum	0.089	
LF(80_Avrerage),	Maximum	0.254	
LF(80_Avrerage),	Average	0.188	
LF(80_Avrerage),	Std.dev.	0.055	
Lj(Avrerage),	Minimum	-1	dB
Lj(Avrerage),	Maximum	-0.5	dB
Lj(Avrerage),	Average	-0.7	dB
Lj(Avrerage),	Std.dev.	0.1	dB
BR(SPL),	Minimum	3.5	dB
BR(SPL),	Maximum	4.3	dB
BR(SPL),	Average	4	dB
BR(SPL),	Std.dev.	0.3	dB
SIL,	Minimum	80.8	dB
SIL,	Maximum	84.8	dB

SIL,	Average	82.6	dB
SIL,	Std.dev.	1.1	dB
AI,	Minimum	1	
AI,	Maximum	1	
AI,	Average	1	
AI,	Std.dev.	0	
Alcons(STI),	Minimum	5.16	%
Alcons(STI),	Maximum	10.1	%
Alcons(STI),	Average	7.76	%
Alcons(STI),	Std.dev.	1.63	%
Density(reflections),	Minimum	4470	/ms
Density(reflections),	Maximum	6131	/ms
Density(reflections),	Average	5726	/ms
Density(reflections),	Std.dev.	440.9	/ms