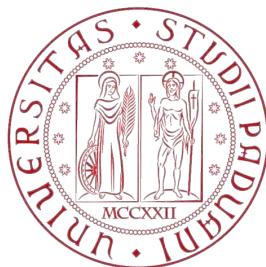


UNIVERSITÀ DEGLI STUDI DI PADOVA



DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

CORSO DI LAUREA MAGISTRALE IN INGEGNERIA DELLA SICUREZZA CIVILE ED
INDUSTRIALE

Tesi di Laurea Magistrale in Ingegneria della Sicurezza Civile ed Industriale

STUDY OF SPEECH INTELLIGIBILITY IN ROOMS

**STUDIO DELL'INTELLIGIBILITÀ DEL PARLATO NEGLI AMBIENTI
CHIUSI**

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Anno accademico 2019-2020

Riassunto

Nell'ambito della prevenzione incendi, nella legislazione italiana, nel D.M. 3.08.2015¹, sezione S - Strategie, capitolo S.7 - rivelazione ed allarme, troviamo che l'impianto di rivelazione incendio e segnalazione allarme incendi (IRAI) nasce con l'obiettivo principale di rivelare un incendio quanto prima possibile e di lanciare l'allarme al fine di attivare le misure protettive (come gli impianti automatici di controllo o estinzione, compartmentazione, evacuazione di fumi e calore...) e gestionali (come piano e procedure di emergenza e di esodo) progettate e programmate in relazione all'incendio rivelato e all'area ove tale principio di incendio si è sviluppato rispetto all'intera attività sorvegliata. Questi impianti devono essere progettati, realizzati e mantenuti a regola d'arte secondo quanto prescritto dalle specifiche regolamentazioni, dalle norme di buona tecnica e dalle istruzioni fornite dal fabbricante.

In particolare, la parte di segnalazione dell'allarme viene gestito dai sistemi EVAC, i quali devono trasmettere informazioni per la protezione della vita in una o più aree specifiche all'interno o all'aperto di una determinata struttura, e con ciò consentire di dare luogo a una rapida e ordinata evacuazione degli occupanti di una o più zone in caso di emergenza. La pianificazione del sistema di allarme vocale deve essere effettuata da persone con qualifiche e/o esperienza relativamente ai particolari requisiti di progettazione. Il punto della questione è quindi l'intelligibilità del messaggio di emergenza trasmesso dagli altoparlanti. Tale requisito è possibile verificarlo sia con metodo soggettivi che con metodo oggettivi i quali sono preferibili.

Con l'obiettivo di analizzare l'efficacia ed efficienza dei sistemi EVAC e una loro possibile progettazione con l'utilizzo di software di simulazioni acustica, si è preso in esame tre aule appartenenti al Dipartimento di Ingegneria Meccanica dell'Università di Padova. Le tre aule in questione sono la M5, M6 ed M10. Rispettivamente due aule piccole ed una grande.

L'intenzione è quella di andare a valutare i parametri acustici necessari a caratterizzare l'ambiente ed i valori di intelligibilità presenti in funzione a diverse tipologie di rumore di fondo

¹ D.M. 3.08.2015: "Approvazione di norme tecniche di prevenzione incendi, ai sensi dell'articolo 15 del decreto legislativo 8 marzo 2016, n. 139"

che possono verificarsi realmente durante il normale svolgimento delle lezioni e quindi, in caso di emergenza, il momento in cui i sistemi EVAC devono dimostrare la loro efficacia.

Dopo una prima parte di ricerca bibliografica e studio delle normative inerenti ai sistemi di segnalazione sonora (capitolo 1) e studio dei parametri fondamentali alla caratterizzazione acustica degli ambienti (capitolo 2) si passa al cuore del lavoro (capitolo 3), ovvero alla presentazione dei parametri ottenuti attraverso le campagne di misurazione effettuate in tutte e tre le aule. Vengono riportati quindi i valori di rumore di fondo misurati in diverse condizioni, il valore dello STIPA, e il tempo di riverbero. Tutte le misurazioni sono state effettuate conformemente a quanto previsto dalle rispettive normative di riferimento.

In riferimento all'indice STIPA, vengono riportati i valori risultanti dall'aggiunta attraverso il file fornito dalla Nti delle diverse combinazioni di rumore di fondo prese in considerazione in quanto lo STIPA lo si è misurato in condizioni di quiete. Dai valori risultanti si sono potute fare delle considerazioni fondamentali riguardanti i sistemi EVAC. Facendo riferimento alla ISO 7240-19 si è potuto individuare in quali combinazioni di rumore di fondo i requisiti minimi richiesti vengono soddisfatti ai fini di una progettazione dei sistemi EVAC (media STIPA 0.50 e minimo valore STIPA 0.45). I risultati confermano che, come si era già pensato in funzione all'esperienza da studente e da professore, che in condizioni di normale svolgimento delle lezioni i requisiti minimi richiesti dalla normativa non vengono soddisfatti. È importante ricordare le misurazioni sono state effettuate nelle condizioni migliori dell'ambiente circostante, ovvero con poca presenza di studenti e senza la presenza di attività antropiche esterne. Ne risulta quindi che i valori negli altri periodi dell'anno sono diversi se non peggiori di quelli individuati.

Si prosegue quindi alla parte del lavoro riguardante la modellazione degli ambienti attraverso un software di simulazione acustica al fine di individuare l'approccio migliore nel caso in cui si volesse andare ad effettuare una progettazione dei sistemi EVAC. Il software preso come esempio è I-Simpa, una GUI in fase di sviluppo creata dall'UMRAE (Environmental Acoustics Research Unite) dell'Istituto francese di scienza e tecnologia per il trasporto, lo sviluppo e le reti (Ifsttar). Poiché gli ambienti studio sono complessi è stato necessario effettuare prima una modellazione dei volumi attraverso AutoCAD a partire dalle piante fornite dall'Ufficio Tecnico dell'Università e con l'integrazione di rilievi in situ per poter riportare le dimensioni in altezza.

Nel capitolo 4 vengono riportate quindi le caratteristiche principali di I-Simpa e delle immagini da confronto tra gli ambienti reali e la modalità in cui sono stati scelti di modellare.

Una volta effettuata la modellazione e validazione dei modelli si procede alla fase di descrizione degli approcci possibili di simulazione e conseguente studio dei risultati ottenuti (Capitolo 5).

I due approcci di studio sono:

- assegnazione dei coefficienti di assorbimento dei materiali di letteratura in funzione della tipologia di materiale a cui appartiene la parete o arredo di riferimento;
- assegnazione di un unico coefficiente di assorbimento agli elementi ottenuto dal tempo di riverbero medio misurato.

Vengono quindi effettuate le simulazioni acustiche secondo i due codici di calcolo forniti da I-Simpa, ovvero il codice SPPS (fondato sul ray-tracing) e il codice TCR (secondo la teorica classica di riverberazione).

Dai risultati si è potuto osservare che alla prima simulazione si ottengono, in termini di tempo di riverbero, valori diversi da quelli effettivamente misurati in entrambi gli approcci di studio. Questa differenza, nel caso di simulazioni con materiali differenziati, può essere dovuta al fatto che non sempre è possibile trovare i corretti valori dei coefficienti di assorbimento dei materiali in quanto nelle schede tecniche, i fornitori non sono obbligati a riportare tali valori, come succede invece nel caso della resistenza al fuoco.

Nel caso di assegnazione di unico coefficiente di assorbimento ottenuto dai tempi di riverbero medi misurati, l'errore è dovuto al fatto che non sappiamo esattamente come lavora il software in questione. Questa problematica è comunque influente anche nel caso di differenziazione dei materiali. È opportuno quindi effettuare una calibrazione dei modelli e conseguenti nuove simulazioni. Al momento delle nuove simulazioni si è visto che nuovamente non si ottengono i valori misurati, ma in questo caso le differenze tra i parametri di riferimento sono molto più contenute. Questo vale con entrambi i codici di calcolo forniti dal software.

Si è visto però che si hanno differenze più elevate nel campo delle basse frequenze, in corrispondenza delle alte frequenze invece i valori ottenuti si avvicinano molto a quelli misurati.

Questo è molto evidente anche in funzione del volume dell'ambiente. Infatti, nel caso della M10, aula grande, si hanno differenze molto minori rispetto a quelle ottenute nella M5 ed M6 che sono due aule piccole. Questo perché gli ambienti piccoli risentono maggiormente delle

risonanze modali. È fondamentale quindi la valutazione della frequenza di Schroeder che impone il limite di applicabilità delle equazioni della teoria dell’acustica classica. Si può quindi capire che I-Simpa non modellizza le risonanze modali.

Altra cosa fondamentale è che, riguardo i due codici di calcolo di simulazione si è notata una differenza nella distribuzione dei tempi di riverbero all’interno degli ambienti. Ovvero, nel caso del codice SPPS, come succede nella realtà, i valori di tempo di riverbero simulati variano in funzione della posizione del ricettore. Nel caso del codice TCR invece, viene riportato un unico valore per tutto l’ambiente di tempo di riverbero.

Si può dire quindi che, ai fini di una progettazione EVAC, nel caso in cui la situazione fosse di progettazione, con nuova realizzazione dell’ambiente, è importante effettuare misurazioni intermedie dei parametri acustici ai fini di una calibrazione sempre migliore del modello. Altrimenti, nel caso di edifici esistenti la soluzione è quella di andare ad intervenire sull’apparecchiatura una volta installata per poter avere un sufficiente livello sonoro in caso di emergenza.

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List of Abbreviations

a.d.a. Acoustically Distinguishable Areas

s.s.e.p. Sound System for Emergency Purposes

EVAC Sistema di allarme vocale per scopi di emergenza

T₃₀ Reverberation time obtained from the decay curve from -5 dB to -35 dB

T₂₀ Reverberation time obtained from the decay curve from -5 dB to -25 dB

T₁₀ Reverberation time obtained from the decay curve from -5 dB to -15 dB

STI Speech Transmission Index

STIPA Speech Transmission Index Public Address

TCR Théorie Classique de la Rèverbération

SPPS Simulation de la Propagation de Particules Sonores

Introduction

The study of room acoustics has an important function in the evaluation and design of EVAC systems, systems necessary for an orderly exodus of people from an emergency situation.

This work, after an initial study on the types of alarm sound systems and the acoustic parameters on which they depend to perform their function, aims to evaluate the main parameter that influences the effectiveness and efficiency of an EVAC system, i.e. the intelligibility of speech, in three classrooms of the Department of Mechanical Engineering of the University of Padua, under different conditions of background noise and the compliance of this parameter with the fundamental standard of alarm systems (UNI ISO 7240-19). The aim is then to study the best approach for the design of EVAC systems through 3D modelling of classrooms in question, thanks to the use of AutoCAD, and acoustic simulations using I-Simpa software. From the data obtained from the simulations it will be possible to make comparisons with the data measured in situ, evaluate the differences and identify the best method.

1 – Emergency alarm systems

This first chapter will identify the types of existing emergency alarm systems and the corresponding characteristics they must have. Specifically, sound and voice signal systems will be analysed. They differ according to the type of sound they emit, that is a warning siren in the first case and a spoken message in the second case.

1.1 Sound alarm system

Sound signals that are diffused in public areas and/or workplaces (for safety reasons) can be divided into three categories according to their function and degree of emergency. The three categories are:

- Warning signals: for a predeterminate group of people and it indicates the need to undertake preventive and/or preparatory actions.
- Emergency signals: for predeterminate group of people too and it indicates the need to undertake urgent protection and/or rescue actions.
- Emergency evacuation signals: for all people present in a certain area and it indicates the need to leave the area immediately.

To guarantee their effectiveness, they must have the following characteristics:

- the audibility in all conditions and by all parties potentially concerned
- they must be immediately recognizable.

The audibility of signals depends on intrinsic characteristics, that is, the specific physical properties of the given signal (on which its recognizability also depends), and the characteristics of the environment in which the signal is broadcast and the people to which it is directed.

The intrinsic characteristics that determine the audibility of a signal are:

- the sound pressure level SPL;
- temporal characteristics (e.g. continuous or intermittent sound);
- spectral characteristics.

The characteristics of the environment that affect audibility are:

- Sound pressure level and spectral characteristics of ambient noise [dB(A)]. These parameters are for close and open environment;
- Reverberation time T60 [s]. this parameter is for close environment and intermittent signal.

It is also necessary to keep in mind the type of people to whom the sound signal is directed that they may be hearing impaired workers and/or public and worker wear ear defender.

The criteria to be satisfied for the audibility of the signal are established by UNI EN ISO 7731:2009² in which, depending on the characteristics of the environmental noise (sound level and its spectral content) and the person or group of persons concerned, the sound level and the spectral content of the alarm signal are analysed and defined.

The immediate recognizability of a signal depends on its intrinsic characteristics and in order to have this characteristic must be:

- different from other sound or original present in the same environment;
- unambiguous (pre) established meaning.

It is therefore important to have a correct acoustic design that takes into account the given situation when defining spectral and temporal characteristics of the signal as well as the sound level.

The risk of panic caused by the alarm signal should also be taken into account. The shock effect should be avoided, and this may be possible by predicting that the initial signal strength will rise rapidly from a not too high level.

1.2 Voice alarm system

Complex or potentially critical situations require the s.s.e.p. (Sound System for Emergency Purposes) sound system to be supported or replaced.

² UNI EN ISO 7731:2009: “Ergonomics-danger signals for public and work areas-Auditory danger signals”

Messages from voice signal systems can be activated automatically or manually and provide a quick, orderly and safe evacuation of the occupants of one or more specified areas, indoors or outdoors. This type of signal works in automatic mode when connected to a dedicated fire detection system and in manual mode when an operator (competent person/format) controls the transmission of messages live and/or pre-recorded directly from a control centre.

When used in combination with the voice signalling system, the same loudspeakers can be used for the transmission of voice messages, alarm signals conforming to UNI EN ISO 7731:2009, emergency evacuation signals conforming to ISO 8201³.

The main purpose of the design of the signal are:

1. the acoustic signals are audible. UNI ISO 7240-19⁴ prescribes that, in all positions, the Sound Level must be greater than 65 dB(A) and less than 105 dB(A). In addition, it must be 10 dB higher than the Ambient Noise Level.
2. the spoken messages are intelligible. This requirement may be evaluated on the responses of a given group of listeners who have undergone pre-testing or using specific instrumentation capable of providing objective measurements of certain acoustic parameters such as STIPA (Speech Transmission Index Public Address).

The fundamental standard for the design of an s.s.e.p. system is UNI ISO 7240-19.

1.2.1 UNI ISO 7240-19

UNI ISO 7240-19 specifies the requirements for the design, installation, commissioning, maintenance and operation of voice alarm systems for emergency purposes, intended to diffuse information for the protection of human lives within one or more specific areas, inside or outside, during an emergency.

A well designed and implemented s.s.e.p., being able to provide information in a much more efficient way, limits panic phenomena.

³ ISO 8210: “Acoustics – Audible emergency evacuation signal”

⁴ UNI ISO 7240-19: “Fire detection and alarm system: design, installation, commissioning and service of sound system for emergency purposes”

The basic criteria useful for the planning of s.s.e.p., are in which the things to be identified in the preliminary activity are provided:

- types of danger present;
- areas concerned;
- people potentially affected and the figures to be involved.

Planning must be carried out by persons with specific qualifications and/or experience in relation to the particular design requirements.

The four steps to maintain the efficiency and effectiveness of s.s.e.p., system are:

1. Design;
2. Installation;
3. Commissioning (with first verification of acoustic efficiency);
4. Operation and maintenance, with periodic (every 6 month and annual) acoustic checks.

The s.s.e.p. should allow the transmission of intelligible information on the action to be taken for the protection of life in one or more emergency loudspeaker areas. The acoustic alarm signals must be distributed through the acoustically distinguishable zones by means of a loudspeaker system.

Consideration should be given to the need to distribute alarm signals for people with hearing impairments by means other than loudspeakers such as visual alarm devices.

The s.s.e.p. shall be interconnected with a system of detecting and signalling fire alarms where present.

To design s.s.e.p. there are the following criteria:

- when an alarm is activated, the s.s.e.p. must immediately disable or exclude any functions not connected to an alarm condition (if there is a phase evacuation, the function non-emergency transmissions may continue in emergency speaker areas not affected by the emergency at that time);
- must always be available for operation;
- must be able to transmit alarm signals and voice messages to one or more areas simultaneously;
- all messages must be clear, short and unambiguous.

In order to have an effective and efficient s.s.e.p., minimum intelligibility requirements are defined in acoustically distinguishable areas (a.d.a.: subdivision of an emergency loudspeaker zone characterized by a single reverberation time and an ambient noise level).

Method of measurement	Requirements	
	Average speech intelligibility in a.d.a.	Minimum speech intelligibility in a.d.a
STI/STIPA	0.50	0.45
PB 256 words, %	94	91
PB 1000 words, %	77	68
MRT, %	94	90
SII	0.50	0.45

Table 1: Minimum requirements for speech intelligibility in a.d.a. ISO 7240-19

Speech intelligibility requirements are considered minimum requirements, although in some spaces with high reverberation and in areas with very high levels of ambient noise it may be impossible to achieve them. In such cases, an acceptable level of intelligibility should be agreed between the competent authorities and all other interested parties.

Within the a.d.a., s.s.e.p. should satisfy:

- average reverberation time across the 500 Hz, 1 Kz and 2 kHz octave bands is not greater than 1.3 s;
- the reference ambient noise level is less than 65 dBA;
- the sound pressure level of voice messages is greater than 70 dBA Leq, measured over a period not less than 10 s;

The points at which intelligibility is measured must be chosen according to the following requirements:

1. number of measurement points must be equal to or greater than the number specified in the following table:

acoustically distinguishable area m ²	minimum number of measuring points
< 25	1
25÷100	3
100÷500	6
500÷1500	10
1500÷2500	15
More of 2500	15 every 2500 m ²

Table 1:2 Minimum number of measuring points ISO 7240-19

2. the distance between adjacent measuring points must not be greater than 12m
3. the measuring points must be evenly distributed;
4. the height of the measuring points shall be at 1.2 m for seated positions and 1.6 m for standing positions.

Furthermore, it recommends that the voice alarm system should be designed and implemented as a complete system whose essential elements are:

- equipment, manufactured and installed in a workmanlike manner, which is regularly and regularly maintained;
- operating procedures, tailored to the specific reality/activity, according to the Emergency Evacuation Plan;
- training and information programmes aimed at the skills already possessed by the personnel and the characteristics of the people attending the sites.

The design of s.s.e.p. is a complex activity. A considerable help to the management of the acoustic aspects of the design is represented by the calculation potential offered by dedicated simulation software applications which require that the environment to be designed is reconstructed by computer considering the geometric and acoustic aspects. The geometry can be reconstructed by editing the files related to the areas of interest. The acoustics of closed environments will be determined by the sound absorbing characteristics of the internal surfaces and by the furniture present that define the reverberation time. The information on the ambient noise level will be opportunely inserted.

2 - Acoustic parameters

This chapter will introduce the characteristics of the main acoustic parameters necessary for the description of indoor environments.

2.1 Reverberation time

Reverberation time (T_{60}) is the fundamental indicator of a room's acoustic quality. The reverberation time is determined from the decay curve of the sound pressure level as a function of the time at a point in the room after a sound source is switched off.

This decay can be measured, according to the ISO EN 3382-2⁵ with two methods: the interrupted noise method: where for the excitation of the room is used a loudspeaker source; the integrated impulse response method: the source can be a pistol shots, spark gap impulses, noise burst, balloons.

The standard defines reverberation time as the time, in seconds, required for the sound pressure level to decrease by 60 dB at a decay rate (dB per second), indicated by the linear regression of the least squares of the decay curve, over a range from -5 dB to -35 dB below the initial level. In this case the reverberation time will be indicated with T_{30} .

If a 30 dB decay is not available due to the presence of an excessive background noise level, it is possible to refer to the range from -5 dB to -25 dB of the sound decay. In this case the reverberation time with T_{20} will be indicated.

First 5 dB are excluded from the interval to avoid the influence of early particularly strong reflections.

⁵ ISO EN 3382-2: "Acoustics – Measurement of room acoustic parameter. Part 2: Reverberation time in ordinary rooms"

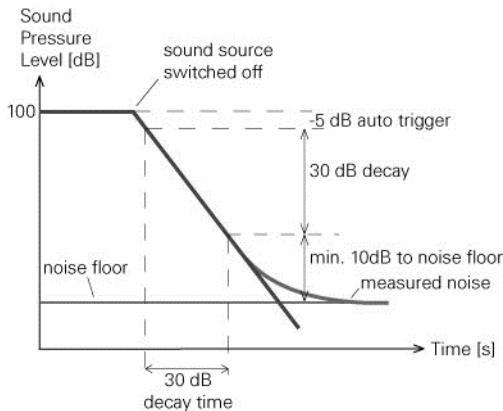


Figure 2:1 Example of extraction of Reverberation time value

The reverberation is that phenomenon present in rooms caused by reflections on the walls of sound waves and it depends on the size of the room and the sound absorption of the walls and the objects it contains. For this reason, it is important to do measurements in a room finished and with furniture because its strongly affects acoustics conditions.

High reverberation has negative consequences as it causes masking effects on the speech intelligibility. There are several reasons to do measurements of reverberation time, for example:

- sound pressure level from noise source;
- speech intelligibility;
- to determine the correct term of absorption coefficient of a room;
- sound insulation measurements;
- sound power measurements.

In order for satisfied listening conditions to occur in a room, the reverberation time must be as close as possible to the optimal values depending on the volume and type of use of the room, distinguishing between rooms intended for listening to speech (classroom, conference room) and rooms intended for listening to music (concert hall, opera house). Excessively low T₆₀ values compared to the optimal value are an indication of a room whose individual sounds are perceived in a distinct way and in which there are considerable differences in the sound pressure level from point to point. Excessively high values, on the other hand, result in unclear listening conditions. Numerous results are available in the literature that provide the optimal reverberation time values for typical categories of rooms intended for listening to speech or music. T₆₀ is generally indicated for a reference frequency (typically 500 Hz or 1kHz) and it

is associated with a correction curve that allows the values to be obtained at the other frequencies of interest.

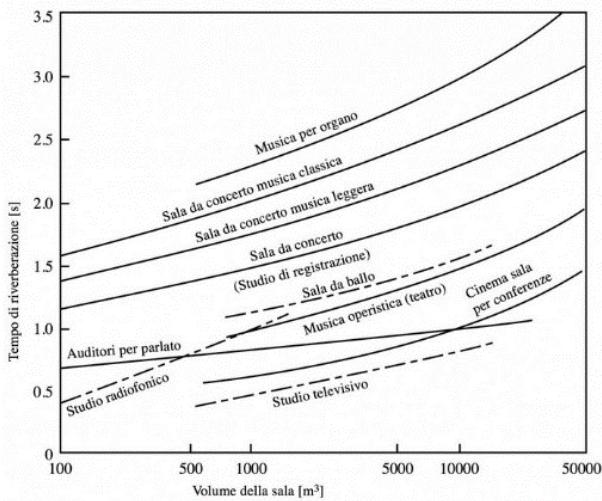


Figure 2:2 Type of events for which a room is appropriate according to reverberation time and volume

ISO EN 3382-2⁶ standard helps us to measure this parameter. It specifies two methods for measuring the TR value: the interrupted noise method: where for the excitation of the room is used a loudspeaker source; the integrated impulse response method: the source can be a pistol shots, spark gap impulses, noise burst, balloons.

2.1.1 UNI 11532-2

UNI 11532-2⁷ defines the noise indicators representing noise quality and reference values for the school sector.

In order to define the objectives to be pursued, it is essential to determine the activity for which the environment is intended according to the categories identified in Table 2:1.

⁶ ISO EN 3382-2: “Acoustics – Measurement of room acoustic parameter. Part 2: Reverberation time in ordinary rooms”

⁷ UNI 11532-2: “Internal acoustical characteristics of confined spaces - Design methods and evaluation techniques – Part 2: Educational sector”

Category	Activity	Intervention modes
A1	Music	Achieved with integrated design of geometries, furnishings, residual noise control
A2	Speech/conference	
A3	Lesson/communication as spoken/conference (large classrooms) student teacher interaction	
A4	Lesson/communication, including special classrooms	
A5	Sport	
A6	Non-learning areas and spaces and libraries	Achieved with sound absorption and residual noise control

Table 2:1: Category of environments in relation to activity. UNI 11532-2

The optimised reverberation time, T_{ott} , corresponding to a conventional room occupation of 80%, except for category A5, is determined in relation to the intended use of the room and its volume. Table 2:2 shows the formulas for calculating T_{ott} .

Category	80% occupied environment	
A1	$T_{ott,A1}=(0.45\log V+0.07)$	$30 \text{ m}^3 \leq V < 1000 \text{ m}^3$
A2	$T_{ott,A2}=(0.37\log V-0.14)$	$50 \text{ m}^3 \leq V < 5000 \text{ m}^3$
A3	$T_{ott,A3}=(0.32\log V-0.17)$	$30 \text{ m}^3 \leq V < 5000 \text{ m}^3$
A4	$T_{ott,A4}=(0.26\log V-0.14)$	$30 \text{ m}^3 \leq V < 500 \text{ m}^3$
Category	Unoccupied environment	
A6	$T_{ott,A6}=(0.75\log V-1.00)$ $T_{ott,A6}=2.00$	$200 \text{ m}^3 \leq V < 10000 \text{ m}^3$ $V \geq 10000 \text{ m}^3$

Table 2:2 T_{ott} formulas for A1-A5 categories. UNI 11532-2

Figure 2:3 shows the dependence of the optimal reverberation time T_{ott} on the volume in relation to the intended use.

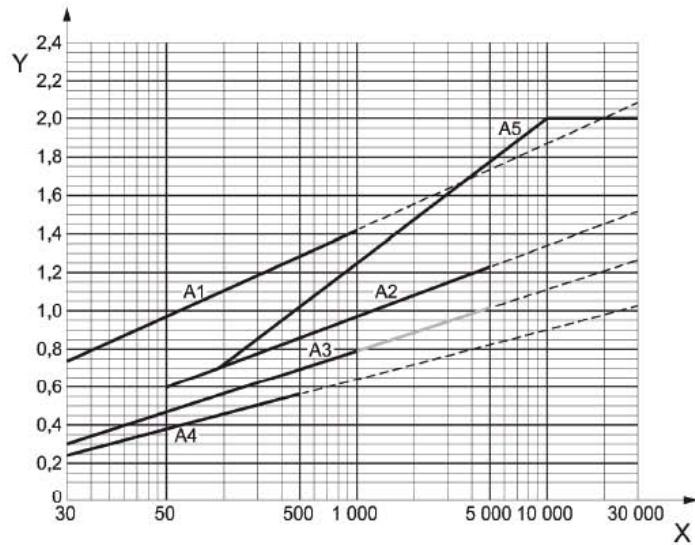


Figure 2.3 Dipendenza del Tott dal volume in relazione alla destinazione d'uso UNI 11532-2. Asse x: Volume – Asse y: Tott

The conversion between the values in the occupied state of the environment obtained with the formulas of table 2:2 and the values in the unoccupied but furnished state, as at the time of verification, must be carried out according to equation 2.1 in the octave bands between 125 Hz and 4000 Hz.

$$T_{inocc} = \frac{T_{occ}}{\left[1 - T_{occ} \frac{\Delta A_{pers}}{0.16V} \right]} \quad (2.1)$$

with T_{occ} is the optimal reverberation time for the 80% occupied room, T_{inocc} is the optimal reverberation time for the unoccupied room (measurement result), V is the room volume and ΔA_{pers} is the additional sound absorption area for people (values in Attachment 1)

2.2 Schroeder Frequency

From the reverberation time it is possible to evaluate the Schroeder Frequency, f_s , which is the limit above which acoustic resonance phenomena can be neglected. This limit is defined by the formula 2.2.

$$f_s = 2000 \sqrt{\frac{RT}{V}} \quad (2.2)$$

Below the f_s , the acoustics are dominated by the presence of standing waves. This means that the acoustic behaviour of the room must be studied by solving the wave propagation equations.

Above the f_s the resonance phenomena can be neglected, so it is possible to study the room acoustics using a statistical approach. Above this limit it is possible to divide the sound field into direct and diffuse. The direct sound field is the region in which the sound pressure theoretically decreases by -6 dB when the distance is doubled. The diffuse sound field is the region where the reflected sound predominates, resulting in a uniform sound pressure level in space.

This limit frequency is useful to make it clear that everything below it is affected by error due to the fact that we have no diffuse field. The f_s can be the one resulting from the calculation with the reverberation time of 1000 Hz or, for safety's reason, it can be considered the worst value, i.e. the one with the highest reverberation time.

2.3 Sound absorption coefficient

Sound absorption coefficient is a property of a material and it represent the fraction of incident sound energy that is absorbed by material.

If the material is perfectly reflective, α is equal to 0. If it is perfectly absorbent, α is equal to 1. The equivalent absorption area can be defined by ISO 9613-1⁸ which takes into account air absorption in indoor environments.

Air absorption has great impact at high frequencies while at low frequencies it is negligible.

$$A = \frac{55.3V}{cRT} - 4Vm \quad (2.3)$$

⁸ ISO 9613-1: "Acoustics- Attenuation of sound during propagation outdoor, Part 1: Calculation of the absorption of sound by atmosphere"

with: V volume of the room, RT reverberation time, c is the velocity of sound in air [m/s] and m is the atmospheric absorption coefficient.

And we can define the equivalent sound absorption area A from the following formula (2.4).

$$A = \bar{\alpha} S_{tot} = \sum_{i=1}^n \alpha_i S_i \quad (2.4)$$

2.4 Speech intelligibility

Speech intelligibility is the percent of words or sentences correctly understood. It is almost never 100% and the reasons are:

- masking effect by background noise origin by plant and anthropic or by the non-optimal transmission of the audio system;
- masking effect by reverberation.

Intelligibility depends more on the loss of consonants than on vowels and therefore emphasis is placed mostly on 2 kHz band.

To determine speech intelligibility there are:

- Subjective evaluation method: tests with word lists and questionnaires, phonetically balanced lists, rhyming tests. They are very reliable and validated methods but have the disadvantage of being very complex to manage and expensive. Moreover, they require a lot of post-processing.
- Objective evaluation method: speech transmission index STI, speech interference level SIL, speech intelligibility index SII, percent. of articulation loss of consonants %Al, clarity C50. These are fast and practical methods with a good correlation with intelligibility but have the disadvantage of being indirect measures and some procedures are not easy to implement and are not automated.

Is important to do a measurement del background noise. The best measurement of background noise is during typical use which should be measured as an $L_{(A)T}$ for a representative period.

2.4.1 Speech Transmission Index (STI)

The STI (Speech Transmission Index) aims to objectively quantify the speech intelligibility at a specific location in one environment when speech is produced through a normalised signal at another specific location in the same environment. The STI index is based on the measurement of MTF (Modulation Transfer Function). MTF quantifies the reduction in the modulation index of a test signal, depending on the modulation frequency. For each modulation frequency, the MTF is determined by the ratio between the modulation index of the signal at the listener, m_0 , and the modulation index of the test signal, m_i . A family of MTF curves is determined, in which each curve is relative to each octave band of speech emission and is defined by the values that the modulation index reduction factor m assumes for each modulation frequency present in the envelope of natural speech signals. In the case of STI index measurement, 7 octave bands from 125 Hz to 8 kHz and 14 modulation frequencies between 0.63 and 12.5 Hz in one-third octave intervals are considered. The 98 (7x14) m-values are finally summarised in a single index, the STI, varying between 0 and 1, which represents the effect of the transmission system on intelligibility.

The STI quantifies the combined effect of background noise interference and reverberation on speech intelligibility reduction with and without sound amplification systems.

Standard UNI EN ISO 9921:2004⁹ establishes a relationship between STI value and their subjective assessment in terms of intelligibility for a normal hearing user (table 2:3).

STI	0-0.30	0.30-0.45	0.45-0.60	0.60-0.75	0.75-1
Intelligibility	Bad	Poor	Fair	Good	Excellent

Table 2:3 Relation between STI and speech intelligibility UNI EN ISO 9921:2004

⁹ ISO 9921:2004: “Ergonomics, Assessment of verbal communication”

Another classification of speech intelligibility is provided in IEC EN 60268-16¹⁰ where the typical STI requirements for dedicated applications are provided. This classification can be found in Attachment 2.

2.4.2 Speech Transmission Index for Public Address (STIPA)

STIPA (Speech Transmission Index for Public Address) is a condensed version of STI measurement. This method is based on the use of all 7 frequency bands as in the STI definition but only 12 modulation indices are measured (instead of 98). In this way the time for a single measurement is significantly reduced: from about 15 minutes to about 15 seconds. It is therefore possible to characterize many more points in an environment in a reasonable time.

¹⁰ IEC EN 60268-16: “Sound system equipment - Objective rating of speech intelligibility by speech transmission index”.

3 – The three classrooms of Department of Mechanical Engineering

To assess the speech intelligibility, three classrooms belonging to the Mechanical Engineering Complex of the University of Padua were chosen as the case study. The classrooms are M5, M6 and M10. They can however be characterized as two small classrooms (M5 and M6) and one large classroom (M10).

3.1 Room descriptions

3.1.1 M5

M5 is a small classroom and has the following characteristics:

- capacity: 32 seats
- maximum dimensions: 6.12 m x 6.64 m
- height: 3.00 m
- volume: 107.2 m³

From the surveys carried out it was possible to deduce that the materials present in the classroom, including the furniture, are: wood, linoleum, concrete with plaster, heavy glass for the windows, metal material for the REI door, characteristic material of the blackboards.

Details and dimensions can be found in the plan in the Attachment 2.

3.1.2 M6

M6 is a small classroom and has the following characteristics:

- capacity: 24 seats
- maximum dimensions: 6.02 m x 7.00 m

- height: 3.00 m
- volume: 115.30 m³

From the surveys carried out it was possible to deduce that the materials present in the classroom, including the furniture, are: wood, linoleum, concrete with plaster, heavy glass for the windows that cover an whole wall, metal material for the REI door, characteristic material of the blackboards.

Details and dimensions can be found in the plan in the Attachement 3.

3.1.3 M10

M6 is a large classroom and has the following characteristics:

- capacity: 194 posti
- maximum dimensions: 12.58 m x 16.17 m
- maximum height at the intrados: 8.05 m
- minimum height at the intrados: 6.28 m
- volume: 1414.50 m³

From the surveys carried out it was possible to deduce that the materials present in the classroom, including the furniture, are: wood, linoleum, concrete with plaster, heavy glass for the windows and the emergency doors, concrete glass block metal material for the REI door, characteristic material of the blackboards.

Details and dimensions can be found in the plan in the Attachement 4.

3.2 Acoustic and thermal measurement

Acoustic measurements of reverberation time (T60) and speech intelligibility (STIPA) have been made according to UNI EN ISO 3382-2.

The impulse source method was chosen for the measurement of T60. The source chosen is the bursting of a balloon because it is an easy source to obtain and can be measured safely.

For STIPA measurements it has been chosen to operate in quiet conditions so that the types of background noise to be considered and the new STIPA values can be associated later with the use of the report file provided by Nti.

The number of positions for the measurement of the various acoustic parameters, in accordance with UNI EN ISO 3382-2, have been made in order to have the highest possible accuracy.

	Survey	Engineering	Precision
Source-microphone combinations	2	6	12
Source-positions	≥ 1	≥ 2	≥ 2
Microphone-positions	≥ 2	≥ 2	≥ 3
N. decays in each position (interrupted noise method)	1	2	3

Table 3:1 Minimum numbers of positions and measurements UNI EN ISO 3382-2

At the same time as the acoustic measurements, the temperature, atmospheric pressure and relative humidity were monitored in order to consider the effects of air absorption on sound according to the method described in ISO 9613-1.

It is also important to note the beginning and end of the measurement campaign to understand the amount of time needed for the acoustic characterization of the rooms.

The stumentation used are:

- Nti Audio XL2 analyzer;
- Nti Audio TalkBox (height 1.60 m);
- Microphone Nti Audio M2210 (height 1.20 m, the height of a seated person);
- Balloons;
- Thermo-hygrometric detector.

3.2.1 M5 - 16.01.2020

Start time of the measurement survey: 1:00 p.m.

The following plan shows the positions of the balloon burst for measuring the T60, the TalkBox (located at a distance of 1 m from the wall and in the position where the speaker is normally located) for STIPA measurement and the receiver positions.

The 10 (1-10) measuring points for background noise and STIPA were chosen in a symmetrical position.

For T60, 2 points (2 and 7) were chosen from the 10 measuring points for the other acoustic parameters and 3 burst source positions (A, B and C, 1 m away from the wall).

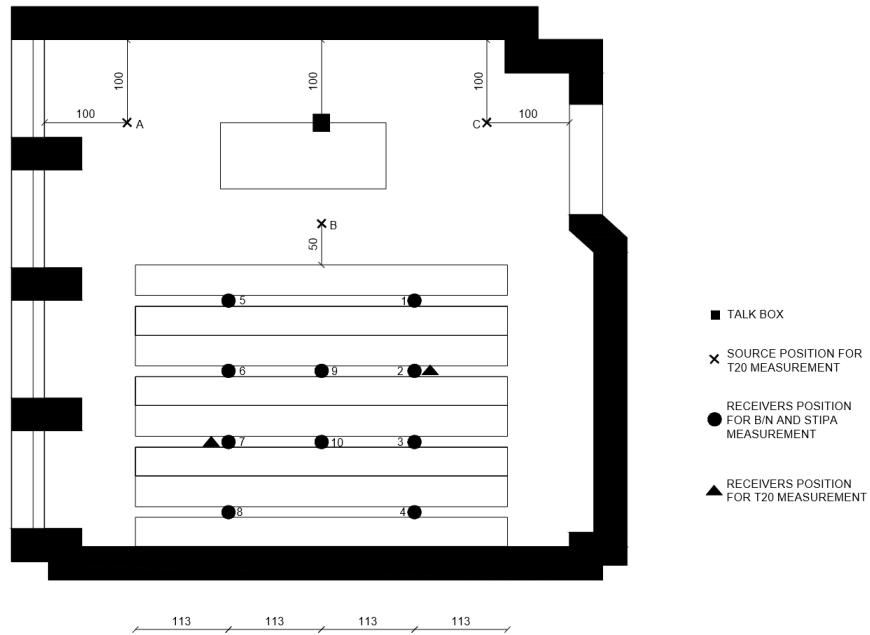


Figure 3:1 Plan of M5 with position of TalkBox, Source for T60 measurement and receivers

In the following paragraphs the results of the measurement campaign are reported.

3.2.1.1 Background Noise measurements

Temperature	19°C
Atmospheric pressure	103200 Pa
Relative humidity	40%
n. people in the room	3

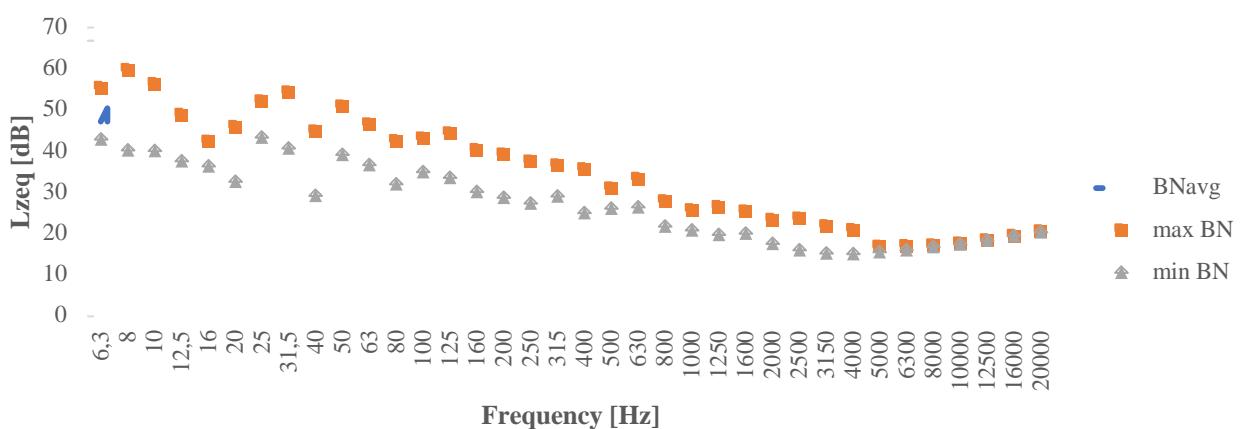
Table 3:2 Environment characteristics at the moment of background noise measurement in M5

The measurement of the background noise value was made at points 1-10 for a duration of 30 s for each measurement point.

The following typical situations were chosen:

1. 1st case: anthropic noise with the addition of noise from active plants (lighting and heating);
2. 2nd case: same noise present in 1st case with the addition of the noise coming from the presence of the projector on (typical situation during the normal course of lessons).

The following graph show the average background noise trend and the maximum and minimum values in each frequency in the 1st case.



Graph 3:1 Values of average, maximum and minimum background noise in 1/3 octave bands 1st case

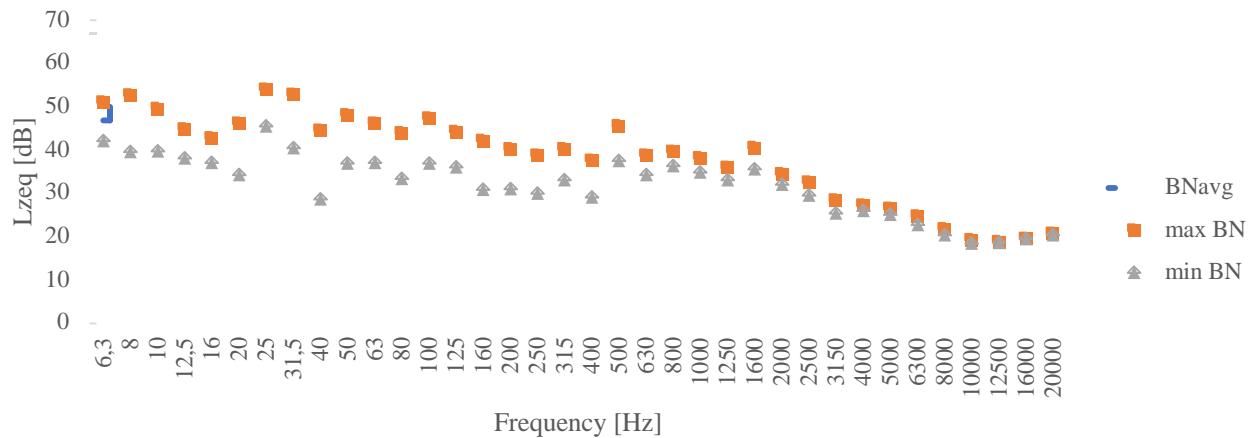
The minimum value is at measurement points 4 with a value of 15.1 dB at the frequency of 4000 Hz.

The maximum value of 59.7 dB was found at point 6 in the 8 Hz band.

In correspondence of the frequency band of 2000 Hz (the band in which emphasis is placed on the consonants necessary for intelligibility) there is a maximum background noise value of 25.7 dB at point 6.

All values in detail are given in Annex A.1.

The following graph show the average background noise trend and the maximum and minimum values in each frequency in the 2nd case.



Graph 3:2 Values of average, maximum and minimum background noise 2nd case

The minimum value is at measurement points 2, 3, 4 and 7 with a value of 18,5 dB at the frequency of 10000 Hz.

The maximum value of 54 dB was found at point 4 in the 25 Hz band.

In correspondence of the frequency band of 2000 Hz (the band in which emphasis is placed on the consonants necessary for intelligibility) there is a maximum background noise value of 38,2 dB at point 9.

All values in detail are given in Annex A.2.



Figure 3:2 Measurement of background noise

3.2.1.2 STIPA measurements

Temperature	19°C
Atmospheric pressure	103200 Pa
Relative humidity	42%
n. people in the room	3

Table 3:3 Environment characteristics at the moment of STIPA measurement in M5

STIPA measurements are made with a source level at 60 dB at points 1-10.

The following tables show the values obtained from the association, using the report file provided by Nti, of STIPA measurements made in quiet conditions with the background noise files of 1st and 2nd case.

For the evaluation of speech intelligibility, the values obtained are compared with those reported in UNI EN ISO 9921:2004 and IEC EN 60268-16.

In addition, STIPA values shall be assessed in terms of average and minimum values in order to assess whether the minimum requirements of ISO 7240-19 are satisfied.

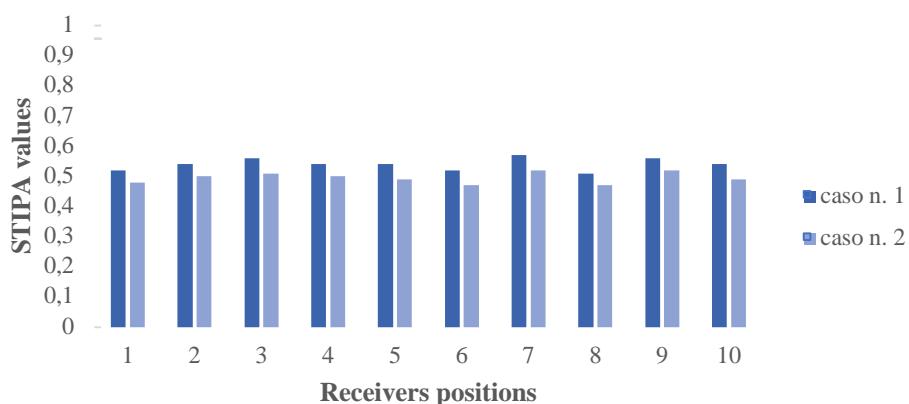
points	1 st case				2 nd case			
	STIPA	IEC 60268- 16	UNI EN 9921:2004		STIPA	IEC 60268- 16	UNI EN 9921:2004	
1	0,52	F	fair		1	0,48	H	fair
2	0,54	F	fair		2	0,50	G	fair
3	0,56	F	fair		3	0,51	G	fair
4	0,54	F	fair		4	0,50	G	fair
5	0,54	F	fair		5	0,49	G	fair
6	0,52	G	fair		6	0,47	H	fair
7	0,57	E	fair		7	0,52	F	fair
8	0,51	G	fair		8	0,47	H	fair
9	0,56	E	fair		9	0,52	G	fair
10	0,54	F	fair		10	0,49	G	fair
			UNI ISO 7240-19					UNI ISO 7240-19
Average	0,54	F	>0,50		Average	0,50	G	>0,50
Min	0,51		>0,45		Min	0,47		>0,45

In conclusion, according to UNI EN ISO 9921:2004 there is a fair speech intelligibility in every point of the classroom in both cases of background noise.

According to IEC EN 60268-16, analysing the average value of STIPA we obtain that this value falls within category F (good quality PA systems) in the 1st case, and for the 2nd case, G that described as the target value for VA (voice alarm) systems.

With reference to ISO 7240-19 we obtain that in both cases of background noise the minimum requirements of intelligibility are satisfied.

The results can be summarised in a histogram showing the STIPA values obtained at each measurement point in the background noise case 1 and 2.



Graph 3:3 STIPA values in the 1st and 2nd case of background noise

So, the increase of background noise can be perceived as affecting the lowering of speech intelligibility.

It is also possible to represent the trend of STIPA in the classroom in the two cases of background noise also through a map graph in which a different colour is associated to each STIPA interval according to UNI EN ISO 9921:2004. In this way it is possible to get an immediate idea of the intelligibility according to the measurement position.

ISO 9921:2004 with 1st case of background noise

Bad 0-0.3	Poor 0.3-0.45	Fair 0.45-0.6	Good 0.6-0.75	Excellent 0.75-1
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Figure 3:4 STIPA measurements

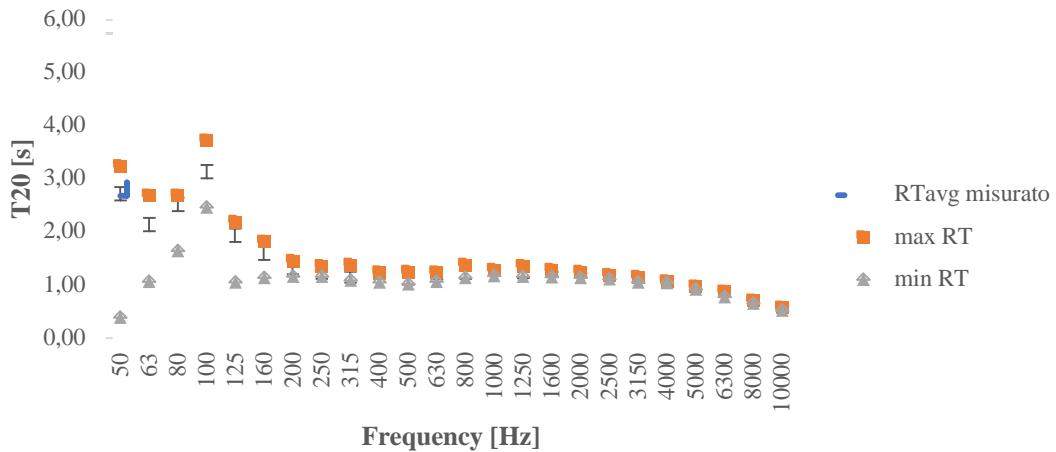
3.2.1.3 Reverberation time measurements

Temperature	19°C
Atmospheric pressure	103200 Pa
Relative humidity	42%
n. people in the room	3

Table 3:6 Environment characteristics at the moment of Reverberation Time measurement in M5

Reverberation time measurements are made in two positions (points 2 and 7) with A, B and C source burst points (balloon). For each source position point, two bursts are made (resulting in two measurements).

The following graph shows the average values of the reverberation time with standard deviation together with the maximum and minimum values (all results are shown in Annex A.3).



Graph 3:4 T20 average, minimum and maximum values measured

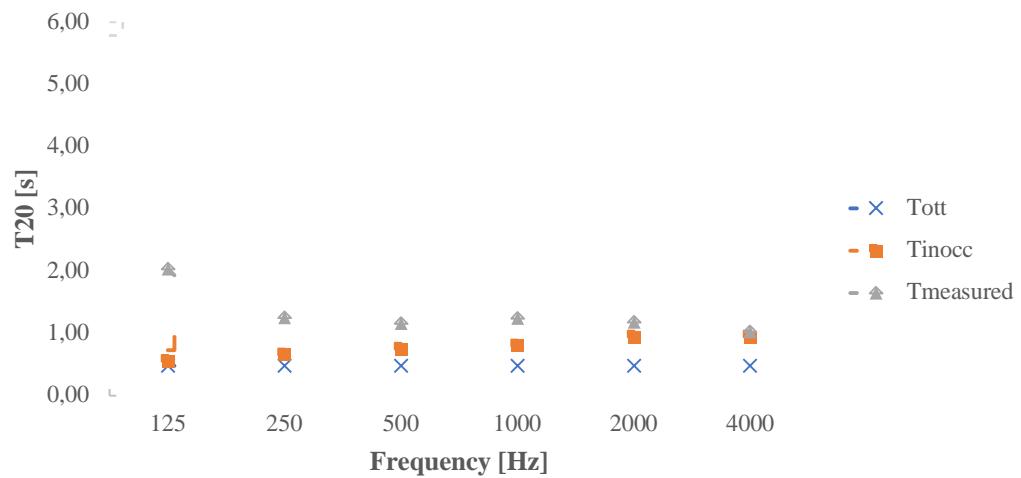
Regarding the requirements of ISO 7240-19 in terms of reverberation time: the average in the 500 Hz, 1000 Hz and 2000 Hz bands must not be greater than 1.3 s we can see that in M5 we have an average value of 1.2 s and therefore less than 1.3 s.

Regarding what reported in UNI 11532-2, the optimal reverberation time for classrooms of category A3 according to the description in table 2:1, results to be according to the equations in table 2:2 for the calculation of T_{ott} and equation 2.1 we obtain the following values:

Frequency [Hz]	T_{occ} [s]	T_{inocc} [s]	$T_{inoccmeasured}$ [s]
125	0,48	0,55	2,04
250	0,48	0,66	1,25
500	0,48	0,75	1,16
1000	0,48	0,80	1,24
2000	0,48	0,94	1,18
4000	0,48	0,94	1,03

Table 3:7 Values of $T_{20\ ott}$, $T_{20\ measured}$ and $T_{20inocc}$ calculated with UNI 11532-2

And graphically



Graph 3:5 Values of $T_{20\text{ ott}}$, $T_{20\text{ measured}}$ and $T_{20\text{inocc}}$ calculated with UNI 11532-2

It is important to calculate the Schroeder Frequency f_s . Considering the worst value obtained in all frequencies we obtain an f_s equal to 331 Hz. The one found based on the optimal reverberation time is 188 Hz.



Figure 3:5 Balloon burst for measurement of reverberation time in M5

End of the measurement survey: 2:10 p.m.

Total duration of the measurement survey: 1:10 hours

3.2.2 M6 - 16.01.2020

Start time of the measurement survey: 2:24 p.m.

The following plan shows the positions of the balloon burst for measuring the T60, the TalkBox (located at a distance of 1 m from the wall and in the position where the speaker is normally located) for STIPA measurement and the receiver positions.

The 5 (1-5) measuring points for background noise and STIPA were chosen in a symmetrical position.

For T60, 2 points (3 and 2) were chosen from the 5 measuring points for the other acoustic parameters and 3 burst source positions (A, B and C, 1 m away from the wall).

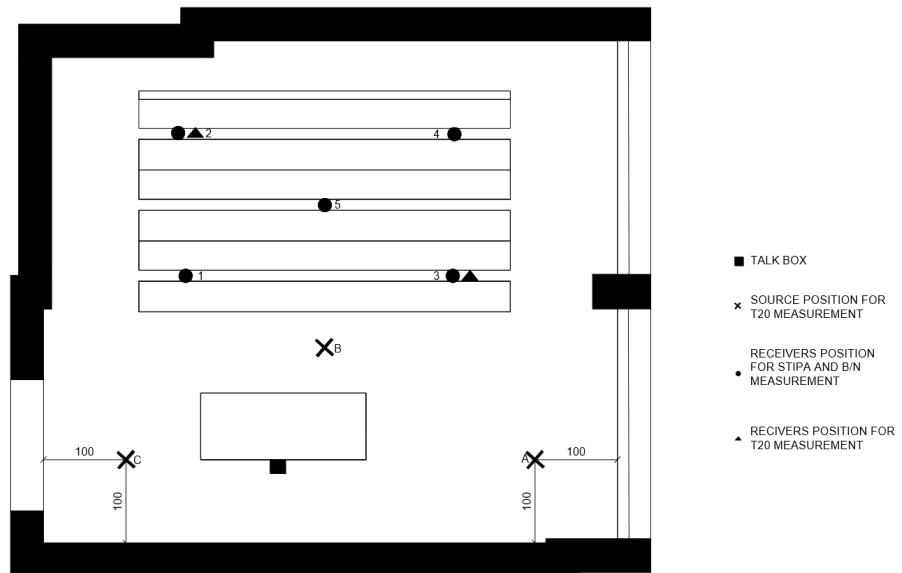


Figure 3:6 Plan of M6 with position of TalkBox, Source for T60 measurement and receivers

In the following paragraphs the results of the measurement campaign are reported.

3.2.2.1 Background noise measurements

Temperature	19°C
Atmospheric pressure	103200 Pa
Relative humidity	39%
n. people in the room	3-2

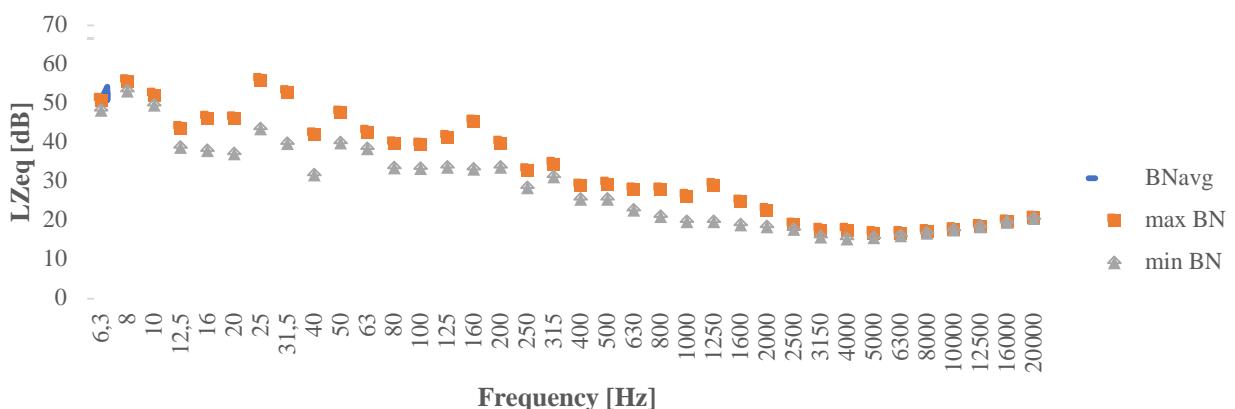
Table 3:8 Environment characteristics at the moment of background noise measurement in M6

The measurement of the background noise value was made at points 1-5 for a duration of 30 s for each measurement point.

The following typical situations were chosen:

1. 1st case: anthropic noise with the addition of noise from active plants (lighting and heating);
2. 2nd case: same noise present in 1st case with the addition of the noise coming from the presence of the projector on (typical situation during the normal course of lessons).
3. 3rd case: same noise present in 2nd case with the addition of noise coming from the electronic hand dryer located in the bathroom adjacent to the classroom (incidental situation).

The following graph show the average background noise trend and the maximum and minimum values in each frequency in the 1st case.



Graph 3.6 Values of average, maximum and minimum background noise in 1/3 octave bands 1st case

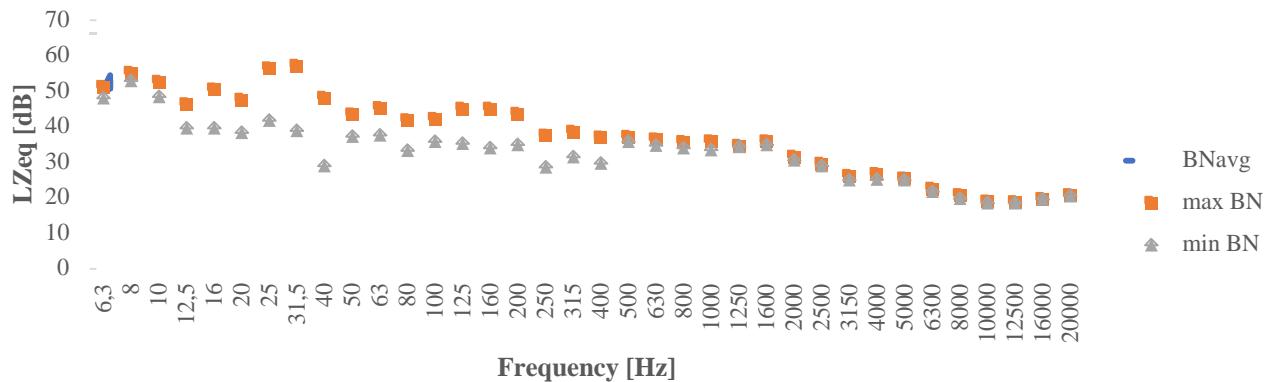
In the 1st case of background noise, the minimum value is at measurement points 5 with a value of 15.3 dB at the frequency of 4000 Hz.

The maximum value of 56.0 dB was found at point 2 in the 25 Hz band.

In correspondence of the frequency band of 2000 Hz (the band in which emphasis is placed on the consonants necessary for intelligibility) there is a maximum background noise value of 22.6 dB at point 3.

All values in detail are given in Annex B.1.

The following graph show the average background noise trend and the maximum and minimum values in each frequency in the 2nd case.



Graph 3:7 Values of average, maximum and minimum background noise in 1/3 octave bands 2nd case

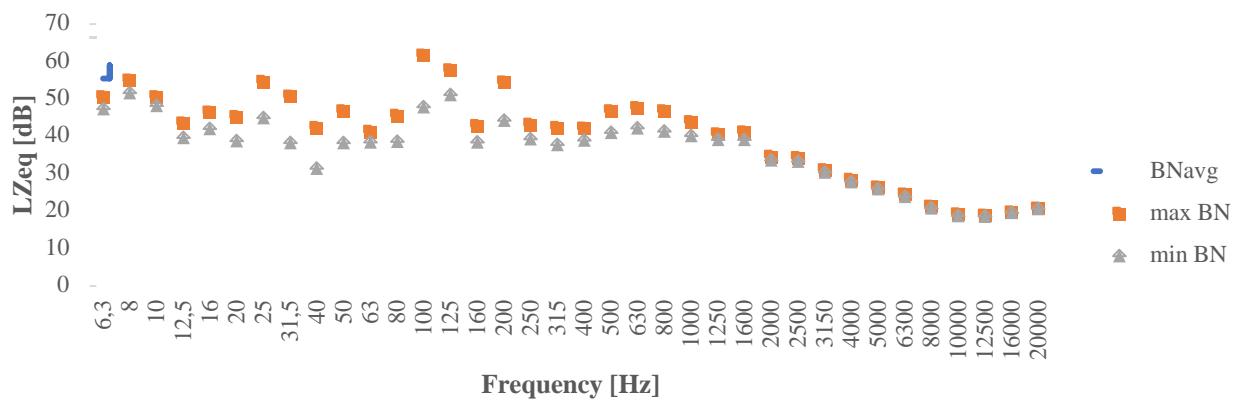
The minimum value is at measurement points 2 with a value of 18.5 dB at the frequency of 10000 Hz.

The maximum value of 57.1 dB was found at point 2 in the 31.5 Hz band.

In correspondence of the frequency band of 2000 Hz (the band in which emphasis is placed on the consonants necessary for intelligibility) there is a maximum background noise value of 31.5 dB at point 1.

All values in detail are given in Annex B.2.

The following graph show the average background noise trend and the maximum and minimum values in each frequency in the 3rd case.



Graph 3:8 Values of average, maximum and minimum background noise in 1/3 octave bands 3rd case

The minimum value is at measurement points 2 and 3 with a value of 18.6 dB at the frequency of 12500 Hz.

The maximum value of 61.5 dB was found at point 1 in the 100 Hz band.

In correspondence of the frequency band of 2000 Hz (the band in which emphasis is placed on the consonants necessary for intelligibility) there is a maximum background noise value of 34.5 dB at point 5.

All values in detail are given in Annex B.3.



Figure 3:7 Measurement of background noise

3.2.2.2 STIPA measurements

Temperature	19°C
Atmospheric pressure	103200 Pa
Relative humidity	39%
n. people in the room	3

Table 3:9 Environment characteristics at the moment of STIPA measurement in M6

STIPA measurements are made with a source level at 60 dB at points 1-5.

The following tables show the values obtained from the association, using the report file provided by Nti, of STIPA measurements made in quiet conditions with the background noise files the three cases.

For the evaluation of speech intelligibility, the values obtained are compared with those reported in UNI EN ISO 9921:2004 and IEC EN 60268-16.

In addition, STIPA values shall be assessed in terms of average and minimum values in order to assess whether the minimum requirements of ISO 7240-19 are satisfied.

1 st case			
points	STIPA	IEC EN 60268-16	UNI EN ISO 9921:2004
1	0,53	F	Fair
2	0,52	G	Fair
3	0,50	G	Fair
4	0,51	G	Fair
5	0,53	F	Fair
			UNI ISO 7240-19
Average	0,52	G	>0,50
Min	0,50		>0,45

Table 3:10 STIPA values in the 1st case

2 nd case			
points	STIPA	IEC EN 60268-16	UNI EN ISO 9921:2004
1	0,50	G	Fair
2	0,49	G	Fair
3	0,47	H	Fair
4	0,48	G	Fair
5	0,50	G	Fair
			UNI ISO 7240-19
Average	0,49	G	<0,50
Min	0,47		>0,45

Table 3:11 STIPA values in the 2nd case

3 rd case			
points	STIPA	Nti Report	UNI EN ISO 9921:2004
1	0,46	H	Fair
2	0,45	H	Fair
3	0,43	I	Poor
4	0,44	H	Fair
5	0,46	H	Fair
			UNI ISO 7240-19
Average	0,45	H	<0,50
Min	0,43		<0,45

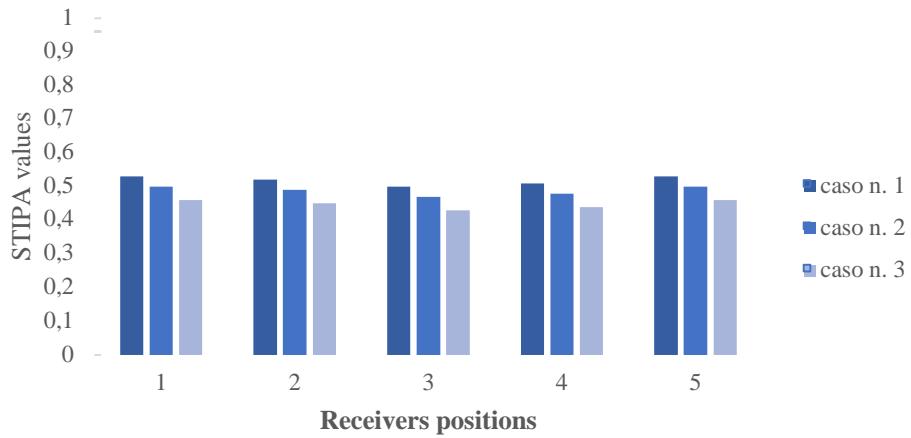
Table 3:12 STIPA values in the 3rd case

According to UNI EN ISO 9921:2004 there is a fair speech intelligibility at all measuring points (in all three cases) except one where there is poor intelligibility (in the 3rd case).

According to IEC EN 60268-16, analysing the average value of STIPA we obtain that this value falls within category G in the 1st case and 2nd case (target value for VA systems), and H in the 3rd case (minimum value for VA systems).

With reference to ISO 7240-19, only in the 1st case of background noise the minimum requirements of intelligibility are satisfied.

The results can be summarised in a histogram showing the STIPA values obtained at each measurement point.

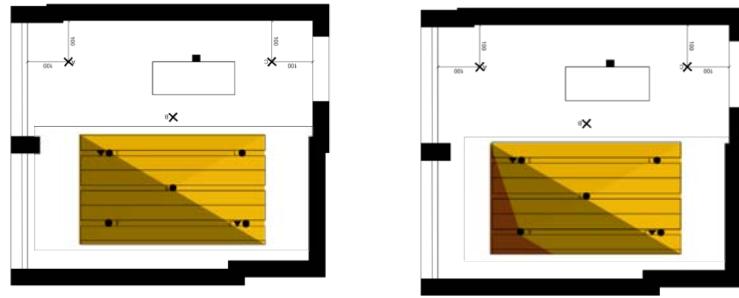


Graph 3:9 Graph of STIPA values in the 1st, 2nd and 3rd case of background noise

So, the increase of background noise can be perceived as affecting the lowering of speech intelligibility.

It is also possible to represent the trend of STIPA in the classroom in the three cases of background noise also through a map graph in which a different colour is associated to each STIPA interval according to UNI EN ISO 9921:2004. In this way it is possible to get an immediate idea of the intelligibility according to the measurement position

In the 3rd case the points with the lowest intelligibility are those located near the window.



Bad 0-0.3	Poor 0.3-0.45	Fair 0.45-0.6	Good 0.6-0.75	Excellent 0.75-1
--------------	------------------	------------------	------------------	---------------------



Figure 3:10 Measurement of STIPA values in M6

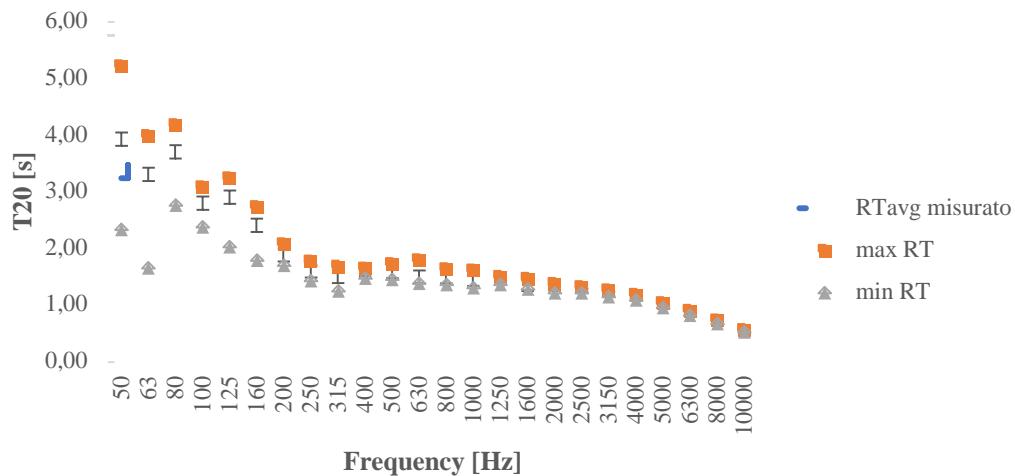
3.2.2.3 Reverberation time measurements

Temperature	19°C
Atmospheric pressure	103200 Pa
Relative humidity	40%
n. people in the room	3

Table 3:13 Environment characteristics at the moment of Reverberation time measurement in M6

Reverberation time measurements are made in two positions (points 2 and 3) with A, B and C source burst points (balloon). For each source position point, two bursts are made (resulting in two measurements).

The following graph shows the average values of the reverberation time with standard deviation together with the maximum and minimum values (all results are shown in Annex B.4).



Graph 3:10 T20 average, minimum and maximum values measured

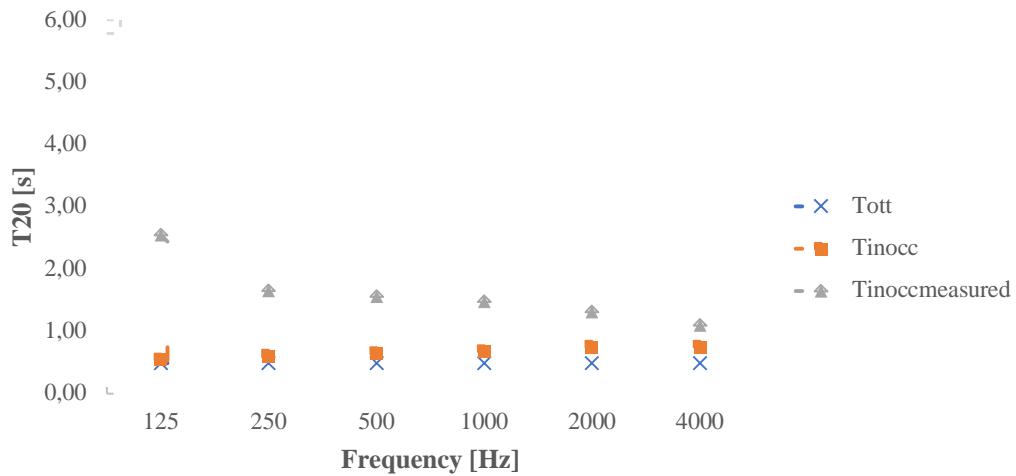
Regarding the requirements of ISO 7240-19 in terms of reverberation time: the average in the 500 Hz, 1000 Hz and 2000 Hz bands must not be greater than 1.3 s we can see that in M6 we have an average value of 1.45 s and therefore greater than 1.3 s.

Regarding what reported in UNI 11532-2, the optimal reverberation time for classrooms of category A3 according to the description in table 2:1, results to be according to the equations in table 2:2 for the calculation of T_{ott} and equation 2.1 we obtain the following values:

Frequency [Hz]	T_{occ} [s]	T_{inocc} [s]	$T_{inoccmeasured}$ [s]
125	0,49	0,54	2,55
250	0,49	0,60	1,66
500	0,49	0,65	1,56
1000	0,49	0,68	1,48
2000	0,49	0,75	1,32
4000	0,49	0,75	1,1

Table 3:14 Values of $T_{20\ ott}$, $T_{20\ measured}$ and $T_{20inocc}$ calculated with UNI 11532-2

And graphically



Graph 3:11 Values of $T_{20\text{ ott}}$, $T_{20\text{ measured}}$ and $T_{20\text{inocc}}$ calculated with UNI 11532-2

It is important to calculate the Schroeder Frequency f_s . Considering the worst value obtained in all frequencies we obtain an f_s equal to 347 Hz. The one found based on the optimal reverberation time is 161 Hz.



Figure 3:11 Balloon burst for reverberation time measurement in M6

End of the measurement survey: 3:05 p.m.

Total duration of the measurement survey: 40 minutes.

3.2.3 M10 – 17.01.2020

Start time of the measurement survey: 4:20 p.m.

The following plan shows the positions of the balloon burst for measuring the T60, the TalkBox (located at a distance of 1 m from the wall and in the position where the speaker is normally located) for STIPA measurement and the receiver positions.

The 12 (1-12) measuring points for background noise and STIPA were chosen in a symmetrical position.

For T60, 3 points (2, 6 and 11) were chosen from the 12 measuring points for the other acoustic parameters and 3 burst source positions (A 1 m away from the wall near the footplate, and B between the two set of desk near the wall with windows).

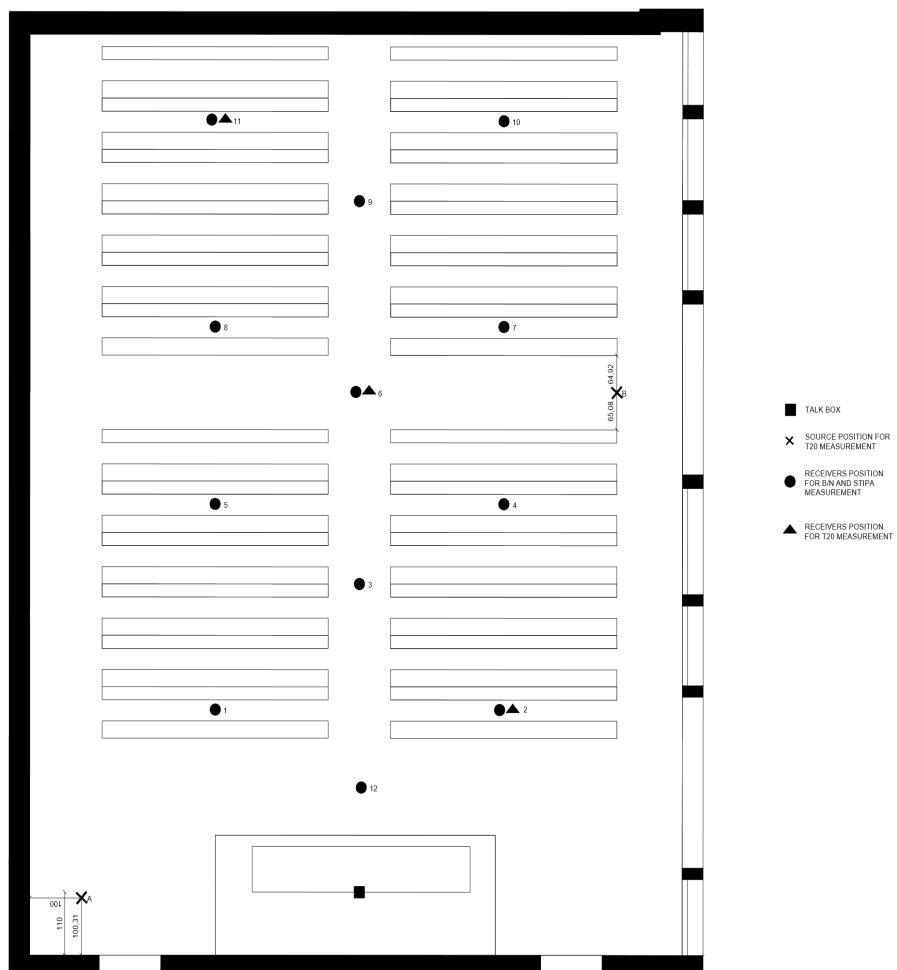


Figure 3:13 Plan of M5 with position of TalkBox, Source for T60 measurement and receivers

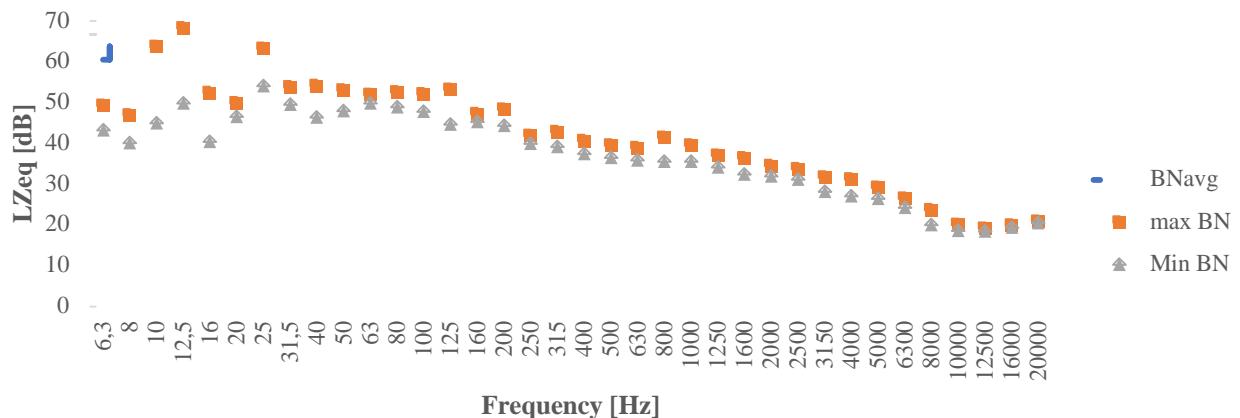
3.2.3.1 Background noise measurements

Temperature	22°C
Atmospheric pressure	102400 Pa
Relative humidity	33%
n. people in the room	2

Table 3:15 Environment characteristics at the moment of background noise measurement in M10

The measurement of the background noise value was made at points 1-12 for a duration of 30 s for each measurement point. The measured background noise is that which is derived from anthropic noise with the addition of noise from active plants (lighting and heating).

The following graph show the average background noise trend and the maximum and minimum values in each frequency.



Graph 3:12 Values of average, maximum and minimum background noise in 1/3 octave bands

The minimum value is at measurement points 2 with a value of 18.1 dB at the frequency of 12500 Hz.

The maximum value of 68.1 dB was found at point 10 in the 12.5 Hz band.

In correspondence of the frequency band of 2000 Hz (the band in which emphasis is placed on the consonants necessary for intelligibility) there is a maximum background noise value of 33.8 dB at point 4.

All values in detail are given in Annex C.1.



Figure 3:124 Measurement of background noise in M10

3.2.3.2 STIPA measurements

Temperature	22°C
Atmospheric pressure	102400 Pa
Relative humidity	33%
n. people in the room	2

Table 3:16 Environment characteristics at the moment of STIPA measurement in M10

STIPA measurements are made first with a source level at 60 dB and then with source level at 70 dB at points 1-12 because the classroom is very noisy and large.

The following tables show the values obtained from the association, using the report file provided by Nti, of STIPA measurements made in quiet conditions with the background noise files the three cases.

For the evaluation of speech intelligibility, the values obtained are compared with those reported in UNI EN ISO 9921:2004 and IEC EN 60268-16. In addition, STIPA values shall be assessed in terms of average and minimum values in order to assess whether the minimum requirements of ISO 7240-19 are satisfied.

Talkbox 60 dB				Talkbox 70 dB			
points	STIPA	IEC 60268- 16	UNI EN 9921:2004	points	STIPA	IEC 60268- 16	UNI EN 9921:2004
1	0,29	U	Bad	1	0,40	I	Poor
2	0,27	U	Bad	2	0,41	I	Poor
3	0,31	U	Poor	3	0,45	H	Fair
4	0,23	U	Bad	4	0,39	J	Poor
5	0,25	U	Bad	5	0,36	J	Poor
6	0,27	U	Bad	6	0,42	I	Poor
7	0,21	U	Bad	7	0,34	U	Poor
8	0,23	U	Bad	8	0,36	U	Poor
9	0,23	U	Bad	9	0,41	I	Poor
10	0,21	U	Bad	10	0,37	J	Poor
11	0,24	U	Bad	11	0,36	J	Poor
12	0,48	G	Fair	12	0,61	D	Good
UNI ISO 7240-19				UNI ISO 7240-19			
Average	0,27	U	<0,50	Average	0,41	I	<0,50
Min	0,21		<0,45	Min	0,34		<0,45

Table 3:17 STIPA values with TalkBox at 60 dB

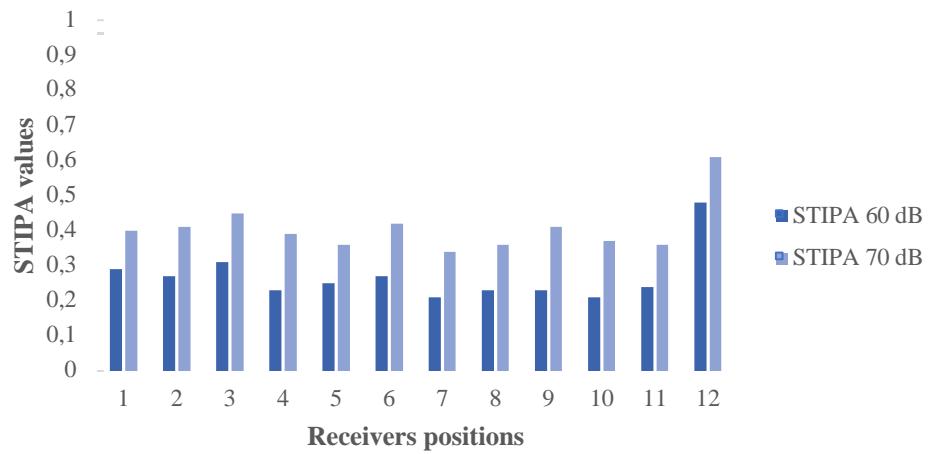
Table 3:18 STIPA values with TalkBox at 70 dB

In conclusion, according to UNI EN ISO 9921:2004 there is a bad and poor speech intelligibility. Only with the TalkBox at 70 dB there is a point (near the Talk Box) with good speech intelligibility.

According to IEC EN 60268-16, analysing the average value of STIPA we obtain that this value falls within category U with the TalkBox at 60 dB, I with the TalkBox at 70 dB.

With reference to ISO 7240-19, in neither case are the minimum requirements satisfied.

The results can be summarised in a histogram showing the STIPA values obtained at each measurement point.



Graph 3:135 STIPA values with TalkBox at 60 dB and 70 dB

It is also possible to represent the trend of STIPA in the classroom with TalkBox at 60 dB and 70 dB through a map graph in which a different colour is associated to each STIPA interval according to UNI EN ISO 9921:2004. In this way it is possible to get an immediate idea of the intelligibility according to the measurement position

TalkBox at 60 dB

Bad	Poor	Fair	Good	Excellent
0-0.3	0.3-0.45	0.45-0.6	0.6-0.75	0.75-1



Figure 3:17 STIPA measurement

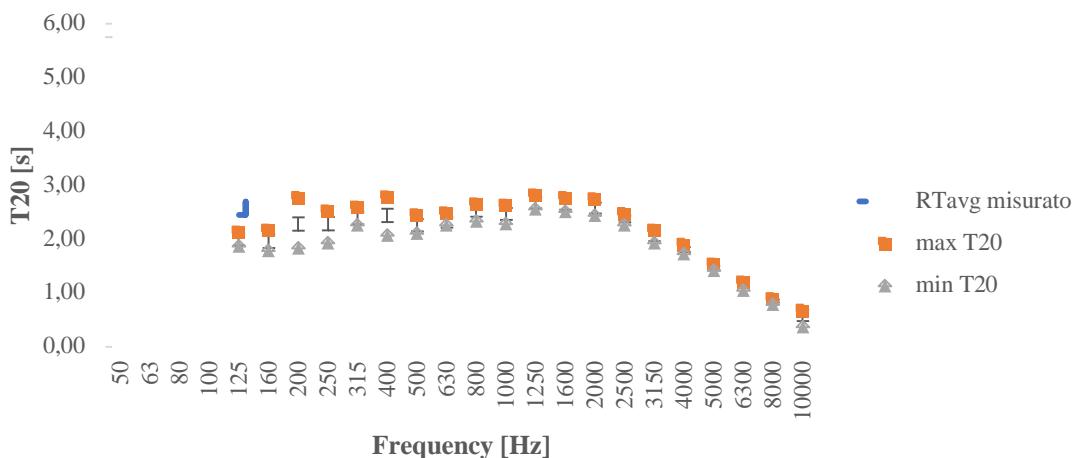
3.2.3.3 Reverberation time measurements

Temperature	22°C
Atmospheric pressure	102400 Pa
Relative humidity	33%
n. people in the room	2

Table 3:19 Environment characteristics at the moment of Reverberation time measurement in M10

Reverberation time measurements are made in three positions in the diagonal of the classroom (points 1, 6 and 3) with A, B source burst points (balloon). For each source position point, two bursts are made (resulting in two measurements).

The following graph shows the average values of the reverberation time with standard deviation together with the maximum and minimum values (all results are shown in Annex C.2).



Graph 3:146 T20 average, minimum and maximum values measured

The absence of data in the frequencies 50-100 Hz is due to the fact that the energy caused by the balloon burst was not sufficient because the classroom is too big. One solution could be to use firecrackers with the necessary safety measures as a source.

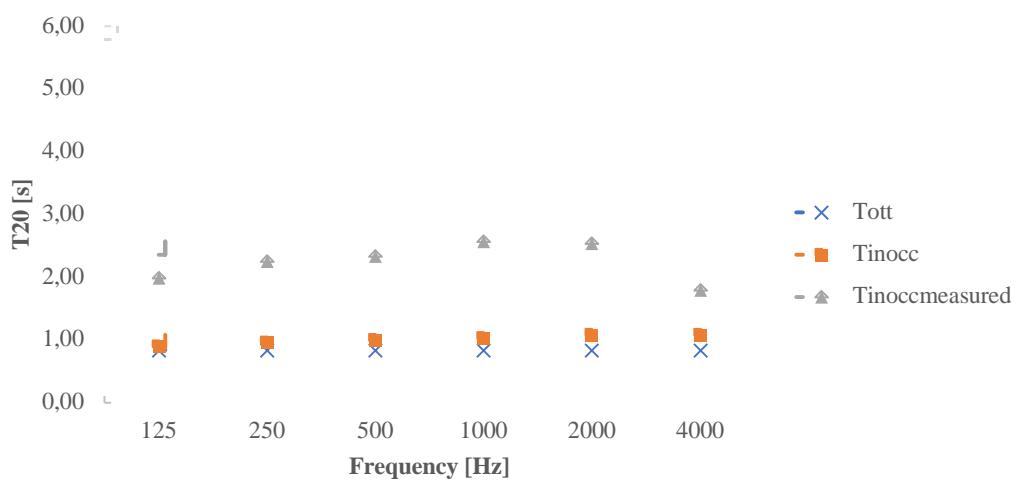
Regarding the requirements of ISO 7240-19 in terms of reverberation time: the average in the 500 Hz, 1000 Hz and 2000 Hz bands must not be greater than 1.3 s we can see that in M10 we have an average value of 2.48 s and therefore greater than 1.3 s.

Regarding what reported in UNI 11532-2, the optimal reverberation time for classrooms of category A3 according to the description in table 2:1, results to be according to the equations in table 2:2 for the calculation of T_{ott} and equation 2.1 we obtain the following values:

Frequency [Hz]	T_{occ} [s]	T_{inocc} [s]	$T_{inoccmeasured}$ [s]
125	0,84	0,89	1,99
250	0,84	0,96	2,25
500	0,84	1,00	2,33
1000	0,84	1,03	2,57
2000	0,84	1,08	2,54
4000	0,84	1,08	1,79

Table 3:20 Values of $T_{20\ ott}$, $T_{20\ measured}$ and $T_{20inocc}$ calculated with UNI 11532-2

And graphically



Graph 1:15 Values of $T_{20\ ott}$, $T_{20\ measured}$ and $T_{20inocc}$ calculated with UNI 11532-2

It is important to calculate the Schroeder Frequency f_s . Considering the worst value obtained in all frequencies we obtain an f_s equal to 87 Hz. The one found based on the optimal reverberation time is 55 Hz.



Figure 3:18 Reverberation time measurement

End of the measurement survey: 5:25 p.m.

Total duration of the measurement survey: 1 hour and 5 minutes.

4 – Modelling the three classrooms

The software used to import the 3D model for acoustic simulations (I-Simpa v. 1.2.3) and the classroom modelling process is presented below.

4.1 I-SIMPA

I-Simpa is a graphical user interface (GUI) created at the Environmental Acoustics Research Unite (UMRAE) of the French institute of science and technology for transport, development and networks (Ifsttar). It is an Opens-Source project and everyone can contribute to the project. It is developed to host three-dimensional numerical codes for the modelling of sound propagation in complex geometrical domains and it is well adapted for energetic models (ray-tracing, sound-particle tracing, theory of reverberation, etc.), it can be extended to use undulatory approaches.

The GUI is distributed with two codes:

- TCR (Théorie Classique de la Rèverbération): based on the classical theory of reverberation proposed by Sabine. It is possible to obtain an evaluation of the diffuse sound field in a single room on the basis of relation of Sabine for the reverberation time and the sound level of the reverberated field.
- SPPS (Simulation de la Propagation de Particules Sonores): based in particle tracing approach. Each particle propagates along a straight line until collision with an object. At each collision, sound particles can be absorbed, scattered, diffused or transmitted. It depends from the nature of the object.

With SPPS can be considered two algorithms:

- Energetic: it considers that the energy of the particle is constant. The number of sound particles decrease along the time.
- Random: the particle energy is different according to the physical phenomena occurring during the propagation. The number of particles should be constant along the time.

The number of sound particles per sources influences the computational time. Each sound particle is followed, at each “Time step” during its propagation, sperimentando l’assorbimento, la riflessione, diffusione durante la “Simulation lenght” fino a quando le particelle scompaiono per la loro energia troppo piccola.

In the energetic approach particles live during their propagation until their energy is below a ratio of the initial energy.

In the random approach, each physical phenomena is applied by considering probabilistic approaches.

About importing the 3D model, I-Simpa is very sensitive to the quality of 3D files. It will not accept geometry with faces intersections, holes between faces. For these reasons is recommended to try to export the model in I-Simpa during the different steps of the model building. To verify that the model works it is important to verify that I-Simpa generate a meshing inside the model by clicking on the “Meshing” button.

To import 3D model from AutoCAD18 to I-Simpa it is necessary to convert the .dwg file in .stl file. This process it can be done by importing the .dwg into an application provided by Autodesk. It is Autodesk FormIt. From FormIt is possible to export the model in .stl and import it in I-Simpa. This process involves the loss of the definition of the layers created in AutoCAD with consequent mesh of the model. It will then be necessary to recompose the layers in I-Simpa to be able to easily assign the characteristics of the material at the time of the simulation.

The following flowchart shows the process used to import the model into I-Simpa.

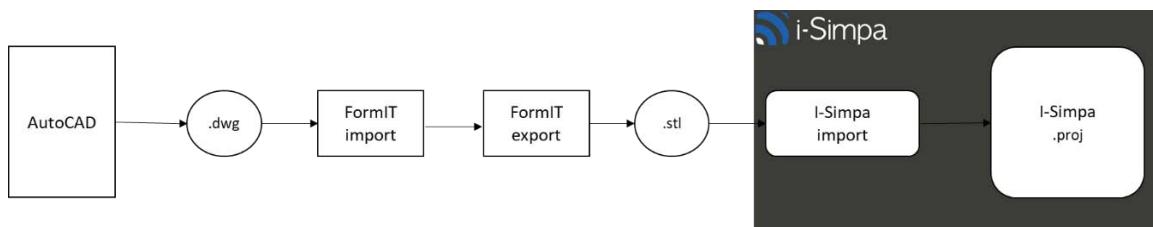


Figure 4:1 Process of import scene in I-Simpa

In this version of I-Simpa (v. 1.2.3) is not possible to do simulation about STI/STIPA, this option will be implemented in future versions.

4.2 The three classrooms

The modelling of the classrooms under study was possible from the plans provided by the Technical Office of the University of Padua combined with in surveys to verify the accuracy of the plans, obtain the height dimensions of the rooms and identify the position and size of the furniture. Below are the photos of the rooms and the corresponding models.

4.2.1 M5

Some simplifications have been made for the furniture: each line that makes up the desks and the bench has been shaped like a cube of furniture size.



Figure 4:2 View of M5

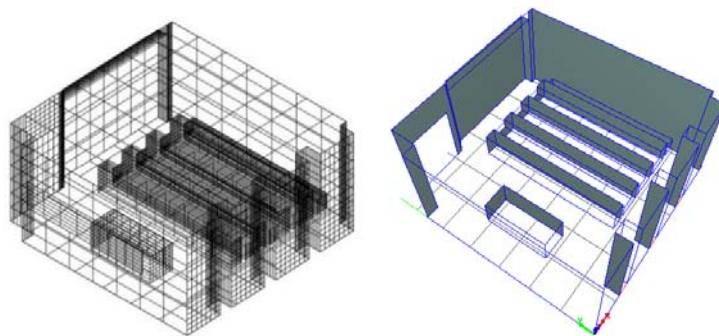


Figure 4:3 Model of M5 in AutoCAD and I-Simpa

4.2.2 M6

Some simplifications have been made for the furniture: each line that makes up the desks and the bench has been shaped like a cube of furniture size.



Figure 4:4 View of M6

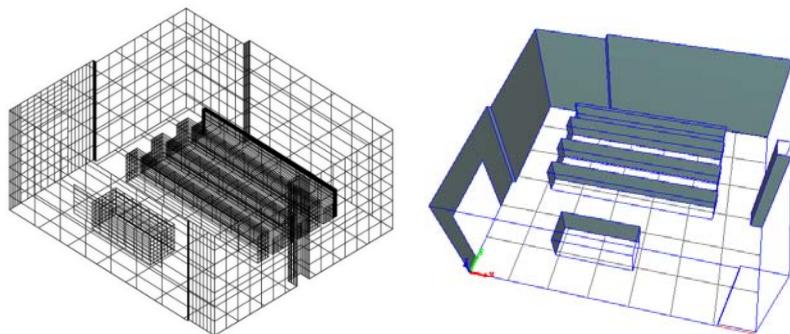


Figure 4:5 Model of M6 in AutoCAD and I-Simpa

4.2.3 M10

In the M10, in addition to simplifying the furnishings (the same as the M5 and M6), it was decided to shape the shed roof beams. In reality they are slightly inclined but given the large size of the classroom we chose to model them straight because it has little impact on the acoustic simulation.



Figure 4:6 View of M10

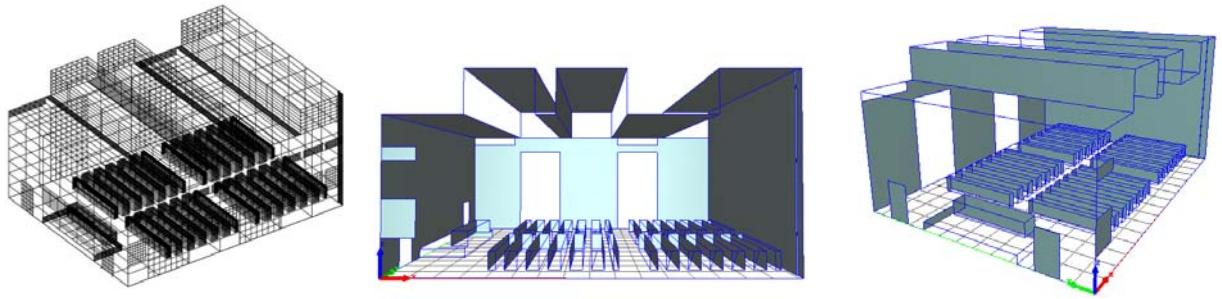


Figure 4:7 Model of M10 in AutoCAD and I-Simpa

5 - Acoustic simulation

The acoustic simulations using I-Simpa are carried out with the sources and receptors in the measuring positions, that is represented in the plans present in §3.2.1, §3.2.2 and §3.2.3.

The balloon source is modelled with a pink noise spectrum with overall sound power level of 100 dB because it is not necessary to replicate the same sound spectrum as the balloon burst because the absorption coefficient of the material is an intrinsic property that does not depend on the type of source.

As input data, the temperature and pressure values present at the time of measurement are set (§3.2.1.3, §3.2.2.3, §3.2.3.3) and simulations are performed following two approaches:

1. Assigning the values of the absorption coefficients ($\alpha_{\text{literature}}$) of the materials present in the literature. Possible situation in the case of a design in which no acoustic measurements are available.
2. Attributing to all walls a single absorption coefficient derived from the average measured reverberation time (α_{avg}).

Both approaches are performed with the TCR method and the SPPS method provided by I-Simpa in order to see the difference between the two calculation methods.

Once the results of the simulations in the two study modes will be obtained, we will proceed to calibrate the models by searching for the values of the absorption coefficients of the materials such that the values measured in reality are obtained.

The calibration process is carried out in the following way: obtained the T20 values from the simulations with $\alpha_{\text{literature}}$ and α_{avg} the difference of the simulated and measured parameters will be evaluated. Through this first simulation it will be possible to identify the maximum error that can be made by the software. From the difference between the simulated and measured parameters it will be possible to obtain the quantity to add or remove to the absorption coefficients of the materials that were initially assigned. These new coefficients will be called $\alpha_{\text{literature calibrated}}$ and $\alpha_{\text{avg calibrated}}$. By performing the simulations again with these new coefficients, it will be possible to evaluate the minimum error that can be made with the software.

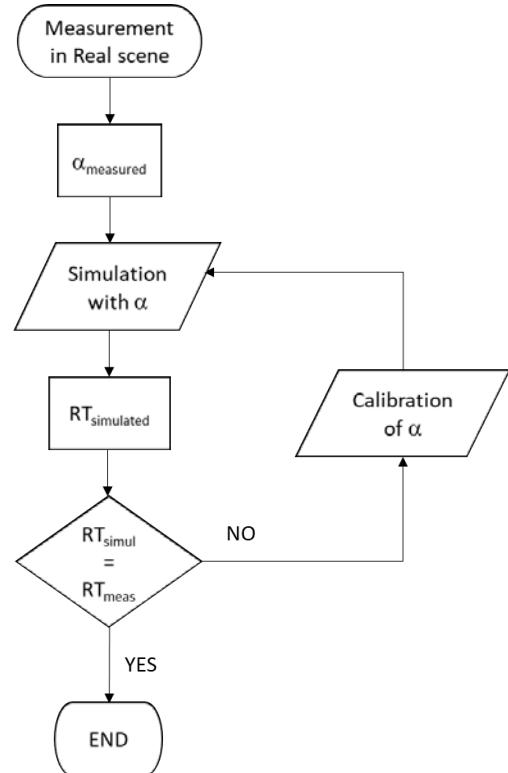


Figure 5:1 Process of calibration

The software calculation settings entered for the two methods are the following:

– SPPS

Active calculation of acoustic transmission	<input checked="" type="checkbox"/>
Active calculation of atmospheric absorption	<input checked="" type="checkbox"/>
Active calculation of diffusion by fitting object	<input checked="" type="checkbox"/>
Active calculation of direct field only	<input type="checkbox"/>
Calculation method	Random
Export surface receivers for each frequency band	<input checked="" type="checkbox"/>
Limit of propagation (10^n)	5
Number of sound particles per source	150000
Number of sound particle per source (display)	0
Radius of receivers (m)	0,31
Simulation length (s)	2
Surface receiver mode	Intensity mapping
Time step (s)	0,01

Table 5:1 I-Simpa parameter in SPPS code

– TCR

Active calculation of atmospheric absorption	<input checked="" type="checkbox"/>
Export surface receivers for each frequency band	<input checked="" type="checkbox"/>

Table 5:2 I-Simpa parameter in TCR code

5.1 α literature

In the design situation, in which it is assumed that the values given by the measurements are not available, the corresponding values of the absorption coefficients found in the literature are assigned to the materials in the classrooms. In the classrooms examined the materials present are:

- Concrete with plaster;
- Wood for benches;
- Large panel glass for windows;
- Glass cement (solo nella M10);
- linoleum;
- blackboard material;
- metal material for REI doors.

It is not easy to find in literature the correct absorption coefficient of the material because it is not sure to be able to find the right description of the material and it is not necessarily possible to find them all for all materials because it is not an obligation on the part of the producer to provide this value in the data sheets. This is the case of the material that defines the REI doors. In the technical data sheets only the sound transmission is given and not the absorption coefficient value of the material, therefore a simplification is made, that is to adopt for this material the absorption coefficients belonging to a heavy door. The values found and assigned are:

	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
Benches (wooden, empty)	0,10	0,09	0,08	0,08	0,08	0,08	0,08
Glass, large panes of heavy plate glass	0,18	0,18	0,06	0,04	0,03	0,02	0,02
Concrete block, with or without plaster, painted	0,11	0,11	0,08	0,07	0,06	0,05	0,05
Layer of rubber, cork, linoleum+underlay or vinyl+underlay stuck to concrete	0,02	0,02	0,02	0,04	0,05	0,05	0,10
Doors (solid wood panels)	0,10	0,07	0,05	0,04	0,04	0,04	0,04
Solid glass blocks	0,02	0,02	0,02	0,02	0,02	0,02	0,02
Slate chalkboard	0,15	0,15	0,11	0,03	0,05	0,03	0,05

Table 5:3 sound absorption coefficient values found in literature

It should be noted that these values are those obtained from laboratory tests according to the procedure described in ISO 354. Since in reality the environmental and also laying conditions are different from the laboratory test conditions, these values are not the real values belonging to the material.

In the next paragraphs we will report the results of the reverberation time obtained from the simulations with the SPPS and TCR codes in the case of absorption coefficient found in the literature with relative percentage difference and in seconds of the simulated reverberation time value with respect to the simulated one for each classroom under study.

Then the values of the absorption coefficients of the calibrated materials will be reported according to what represented in the calibration process described in the flowchart (figures 5:1) and the relative percentage differences with the absorption coefficients of literature reported in §5.1 and the percentage differences between the new reverberation times obtained from the calibration. We can derive the percentage difference between parameter measured and simulated according to the following formula and we can draw a histogram with the result:

$$\Delta X [\%] = \frac{X_{I-Simpa} - X_{measured}}{X_{measured}} \quad (5.1)$$

5.1.1 M5

The materials that are present in M5 are:

- Benches (for furniture);
- Glass, large panels of heavy plate glass (for windows);
- Concrete block, with or without plaster, painted (for walls and ceiling);
- Linoleum (for the floor);
- Solid wood panels (for REI doors);
- Slate chalkboard

To whom are assigned the absorption coefficients present in §5.1.

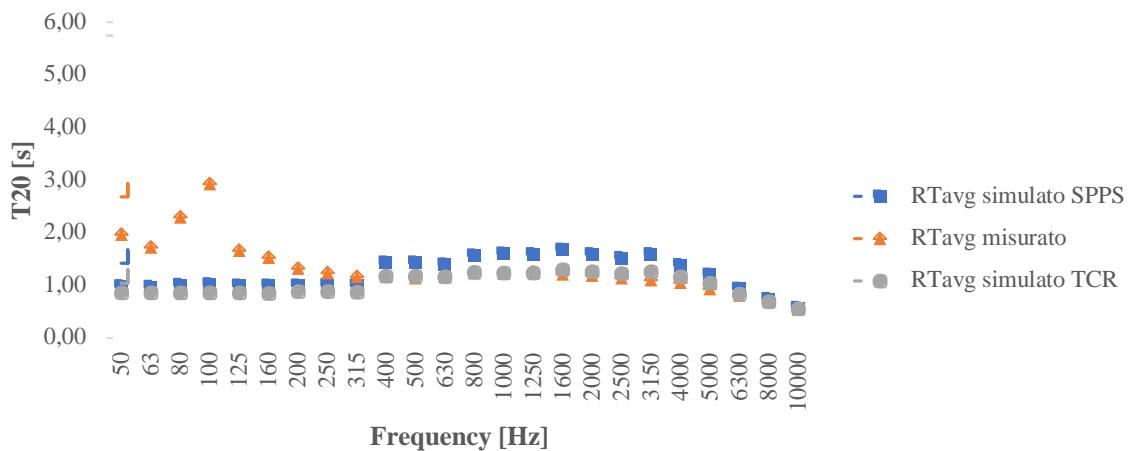
The areas concerning the surfaces to which these materials are assigned are:

Materials	m ²
Benches	55,52
Glass	8,88
Concrete block	108,42
Linoleum	24,43
Solid wood panels	2,68
Slate chalkboard	3,1

Table 5:4 Areas of materials present in M5

5.1.1.1 $\alpha_{M5,lit}$

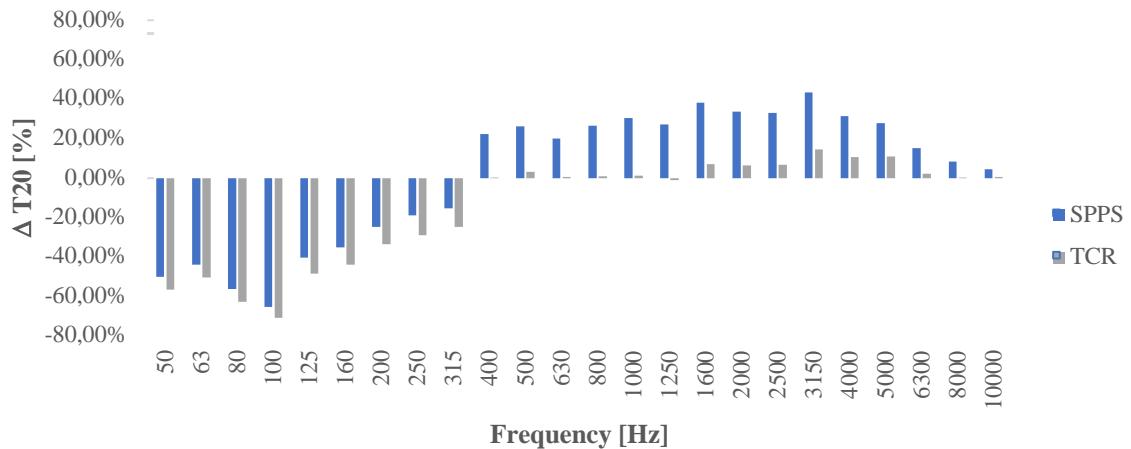
Below are the results obtained from simulations with the SPPS and TCR calculation codes by assigning to the materials the absorption coefficients reported in §5.1. All values obtained are given in Annex A.4.



Graph 5:1 T20 average values measured and simulated with material absorption coefficient not calibrated found in literature with SPPS and TCR codes

Frequency [Hz]	$\Delta T20$ [s] SPPS method	$\Delta T20$ % SPPS method	$\Delta T20$ [s] TCR method	$\Delta T20$ % TCR method
50	0,99	-49,86%	-1,12	-56,44%
63	0,76	-43,82%	-0,87	-50,18%
80	1,29	-56,28%	-1,44	-62,62%
100	1,91	-65,09%	-2,08	-70,72%
125	0,67	-40,40%	-0,81	-48,50%
160	0,53	-34,97%	-0,67	-43,87%
200	0,33	-24,73%	-0,45	-33,52%
250	0,23	-18,76%	-0,36	-28,76%
315	0,18	-15,15%	-0,29	-24,80%
400	-0,26	22,27%	0,00	0,12%
500	-0,30	26,23%	0,04	3,21%
630	-0,23	20,01%	0,01	0,66%
800	-0,33	26,53%	0,01	0,91%
1000	-0,37	30,32%	0,02	1,39%
1250	-0,34	27,35%	-0,01	-1,16%
1600	-0,46	38,33%	0,09	7,07%
2000	-0,40	33,67%	0,08	6,49%
2500	-0,38	32,94%	0,08	6,83%
3150	-0,48	43,58%	0,16	14,48%
4000	-0,33	31,31%	0,11	10,59%
5000	-0,26	27,94%	0,10	11,13%
6300	-0,13	15,29%	0,02	2,36%
8000	-0,06	8,54%	0,00	0,04%
10000	-0,02	4,43%	0,00	0,53%

Table 5:5 Values of percentage difference between T20 simulated and measured with SPPS and TCR codes with sound absorption coefficient found in literature not calibrated



Graph 5:2 Representation of values present in table 5:5

5.1.1.2 $\alpha_{M5,lit,calibrated}$

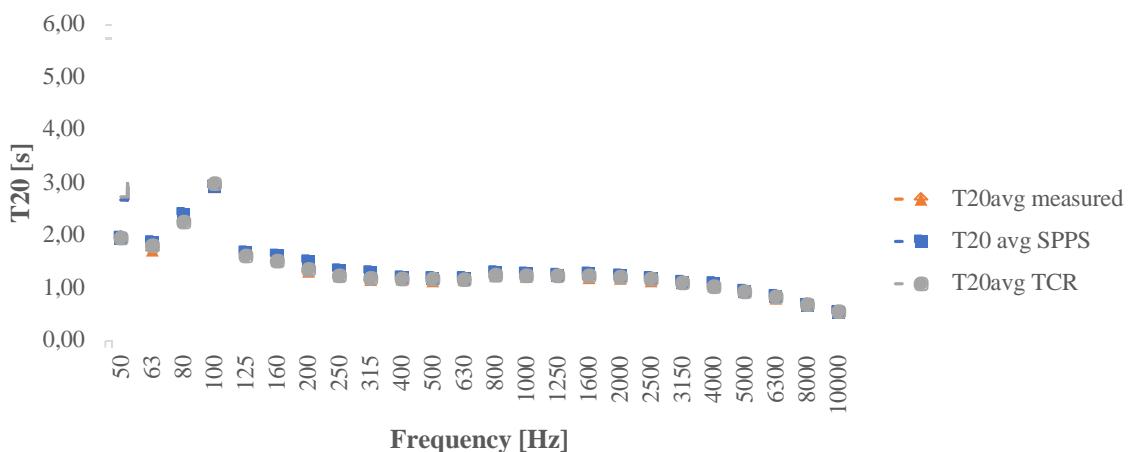
Below are the results obtained from simulations with the SPPS and TCR calculation codes by assigning to the materials the absorption coefficients calibrated. All values obtained are given in Annex A.5.

Frequency [Hz]	α_{SPPS}					
	Benches	glass	Slate chalboard	Concrete block	linoleum	Solid wood panels
50	0,05	0,09	0,08	0,06	0,01	0,05
63	0,06	0,10	0,08	0,06	0,01	0,06
80	0,04	0,08	0,07	0,05	0,01	0,04
100	0,03	0,06	0,05	0,04	0,01	0,03
125	0,06	0,11	0,09	0,07	0,01	0,06
160	0,07	0,12	0,10	0,07	0,01	0,07
200	0,07	0,14	0,11	0,08	0,02	0,05
250	0,07	0,15	0,12	0,09	0,02	0,06
315	0,08	0,15	0,13	0,09	0,02	0,06
400	0,10	0,07	0,14	0,10	0,02	0,06
500	0,10	0,08	0,14	0,10	0,03	0,06
630	0,10	0,07	0,13	0,10	0,02	0,06
800	0,10	0,05	0,04	0,09	0,05	0,05
1000	0,10	0,05	0,04	0,09	0,05	0,05
1250	0,10	0,05	0,04	0,09	0,05	0,05
1600	0,11	0,04	0,07	0,08	0,07	0,06
2000	0,11	0,04	0,07	0,08	0,07	0,05
2500	0,11	0,04	0,07	0,08	0,07	0,06
3150	0,12	0,03	0,05	0,08	0,08	0,06
4000	0,12	0,03	0,04	0,07	0,07	0,06
5000	0,12	0,03	0,04	0,07	0,07	0,06
6300	0,10	0,03	0,06	0,06	0,13	0,05
8000	0,09	0,02	0,06	0,06	0,12	0,05
10000	0,09	0,02	0,06	0,06	0,11	0,04

Table 5:6 Values of materials sound absorption coefficient calibrated with SPPS code

Frequency [Hz]	α_{TCR}					
	Benches	Glass	Slate chalkboard	Concrete block	linoleum	Solid wood panels
50	0,04	0,08	0,07	0,05	0,01	0,04
63	0,05	0,09	0,07	0,05	0,01	0,05
80	0,04	0,07	0,06	0,04	0,01	0,04
100	0,03	0,05	0,04	0,03	0,01	0,03
125	0,05	0,09	0,08	0,06	0,01	0,05
160	0,06	0,10	0,08	0,06	0,01	0,06
200	0,06	0,12	0,10	0,07	0,01	0,05
250	0,06	0,13	0,11	0,08	0,01	0,05
315	0,07	0,13	0,11	0,08	0,01	0,05
400	0,08	0,06	0,11	0,08	0,02	0,05
500	0,08	0,06	0,11	0,08	0,02	0,05
630	0,08	0,06	0,11	0,08	0,02	0,05
800	0,08	0,04	0,03	0,07	0,04	0,04
1000	0,08	0,04	0,03	0,07	0,04	0,04
1250	0,08	0,04	0,03	0,07	0,04	0,04
1600	0,09	0,03	0,05	0,06	0,05	0,04
2000	0,09	0,03	0,05	0,06	0,05	0,04
2500	0,09	0,03	0,05	0,06	0,05	0,04
3150	0,09	0,02	0,04	0,06	0,06	0,05
4000	0,09	0,02	0,03	0,06	0,06	0,05
5000	0,09	0,02	0,03	0,06	0,06	0,05
6300	0,08	0,02	0,05	0,05	0,10	0,04
8000	0,08	0,02	0,05	0,05	0,10	0,04
10000	0,08	0,02	0,05	0,05	0,10	0,04

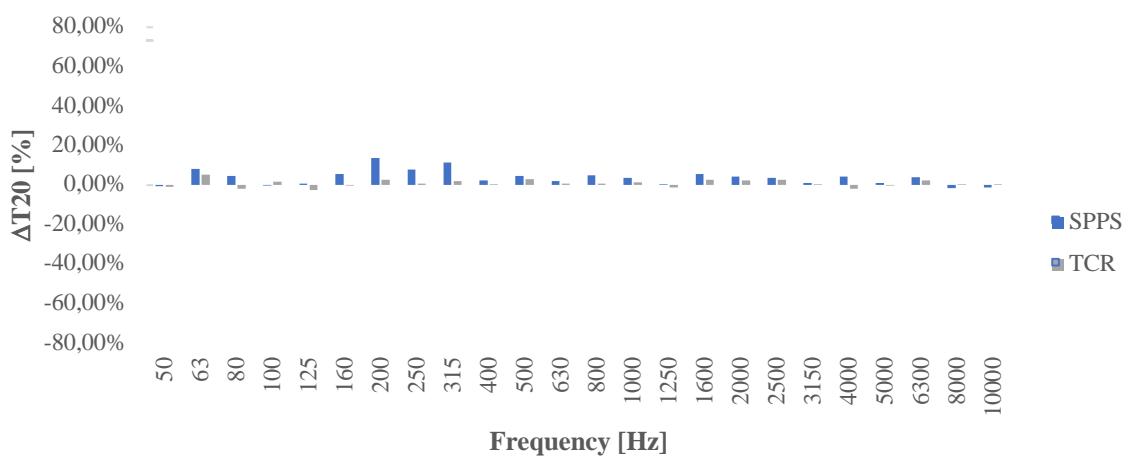
Table 5.7 Values of materials sound absorption coefficient calibrated with TCR code



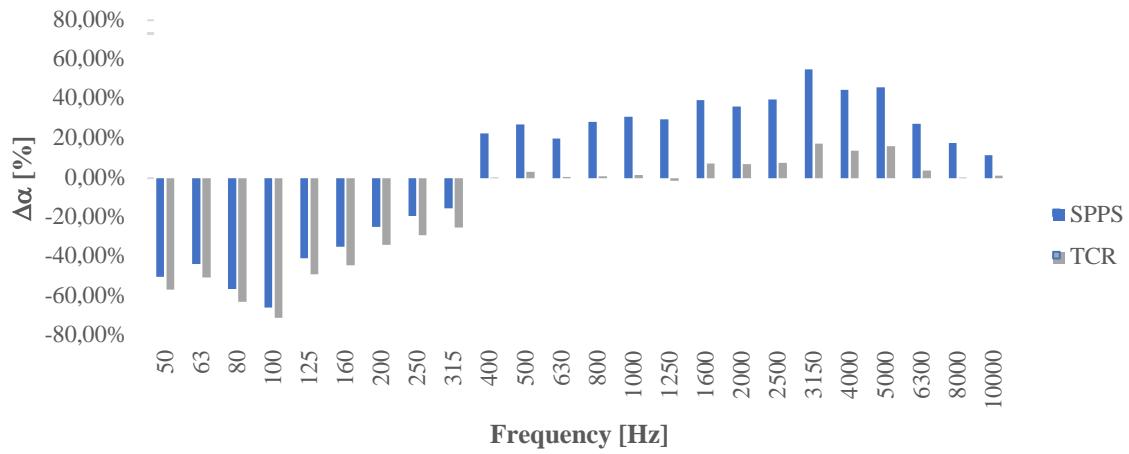
Graph 5.3 T20 average values measured and simulated with material absorption coefficient calibrated found in literature with SPPS and TCR code

Frequency [Hz]	$\Delta T20$ [s] SPPS method	$\Delta T20$ % SPPS method	$\Delta \alpha$ [%] SPPS method	$\Delta T20$ [s] TCR method	$\Delta T20$ % TCR method	$\Delta \alpha$ [%] TCR method
50	0,01	-0,56%	-49,86%	0,02	-0,94%	-56,47%
63	-0,14	8,31%	-43,50%	-0,09	5,36%	-50,21%
80	-0,11	4,76%	-56,09%	0,04	-1,86%	-62,69%
100	0,01	-0,24%	-65,47%	-0,05	1,85%	-70,84%
125	-0,01	0,84%	-40,64%	0,04	-2,57%	-48,61%
160	-0,09	5,69%	-34,58%	0,00	-0,14%	-44,03%
200	-0,18	13,65%	-24,58%	-0,04	2,85%	-33,69%
250	-0,10	7,84%	-19,13%	-0,01	0,65%	-28,96%
315	-0,13	11,46%	-15,41%	-0,02	2,13%	-25,01%
400	-0,03	2,39%	22,77%	0,00	0,12%	0,12%
500	-0,05	4,53%	27,13%	-0,04	3,21%	3,26%
630	-0,02	2,01%	20,20%	-0,01	0,66%	0,67%
800	-0,06	5,04%	28,63%	-0,01	0,91%	0,93%
1000	-0,05	3,81%	31,12%	-0,02	1,39%	1,44%
1250	-0,01	0,41%	29,77%	0,01	-1,16%	-1,21%
1600	-0,07	5,61%	39,45%	-0,03	2,83%	7,50%
2000	-0,05	4,44%	36,38%	-0,03	2,37%	7,04%
2500	-0,04	3,56%	39,70%	-0,03	2,82%	7,66%
3150	-0,01	1,01%	55,13%	0,00	0,33%	17,39%
4000	-0,05	4,32%	44,60%	0,02	-1,91%	13,78%
5000	-0,01	1,14%	45,88%	0,00	-0,23%	16,25%
6300	-0,03	4,15%	27,44%	-0,02	2,36%	3,85%
8000	0,01	-1,59%	17,67%	0,00	0,04%	0,07%
10000	0,01	-1,32%	11,48%	0,00	0,53%	1,29%

Table 5:8 Values of percentage difference between $T20$ simulated with sound absorption coefficient found in literature calibrated and values of percentage difference between average sound absorption coefficient calibrated and measured with SPPS and TCR codes

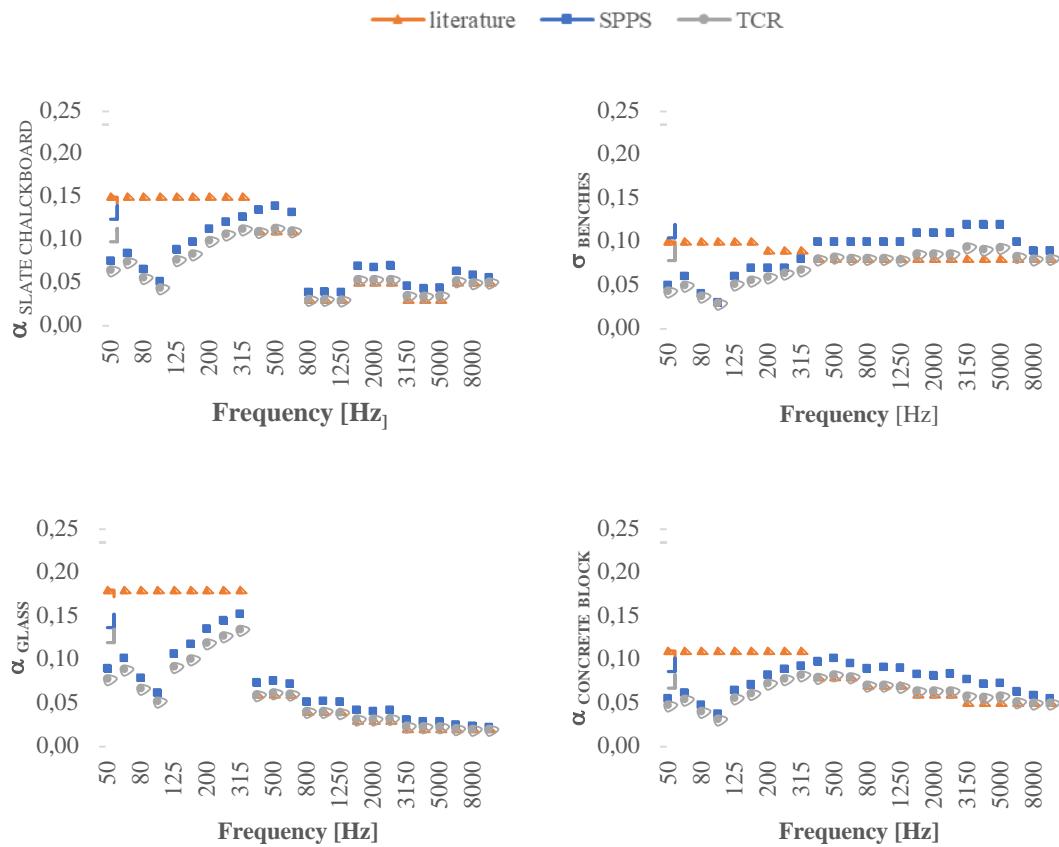


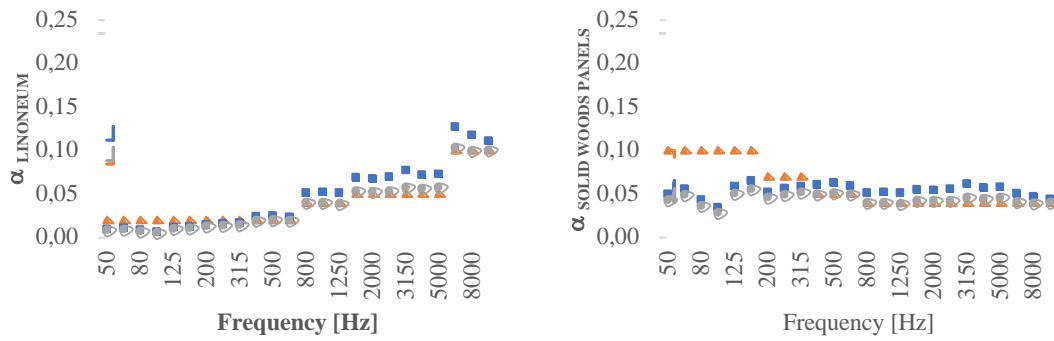
Graph 5:4 Representation of values present in table 5:8



Graph 5:5 Representation of values present in table 5:8

The values of the absorption coefficients of the materials found in the literature (table 5:3) can be reported with the corresponding values obtained from the calibration process in graphs (values of sound absorption coefficient calibrated in table 5:6 for SPPS and 5:7 for TCR), one for each material.





We can observe that at low frequencies, the coefficients found in the literature are higher than those obtained with the calibration process in order to try to obtain the measured reverberation time, as confirmed by graph 5:1 in which the trend of the measured reverberation time is represented and simulated with absorption coefficients of the material not yet calibrated.

At high frequencies, however, the literature coefficients are lower than those obtained with calibration. In particular, we can observe that this change of values takes place around Schroeder's frequency which, as identified in §3.2.1.3, is 331 Hz for the M5 classroom.

5.1.2 M6

The materials that are present in M6 are:

- Benches (for furniture);
- Glass, large panels of heavy plate glass (for windows);
- Concrete block, with or without plaster, painted (for walls and ceiling);
- Linoleum (for the floor);
- Solid wood panels (for REI doors);
- Slate chalkboard

To whom are assigned the absorption coefficients present in §5.1.

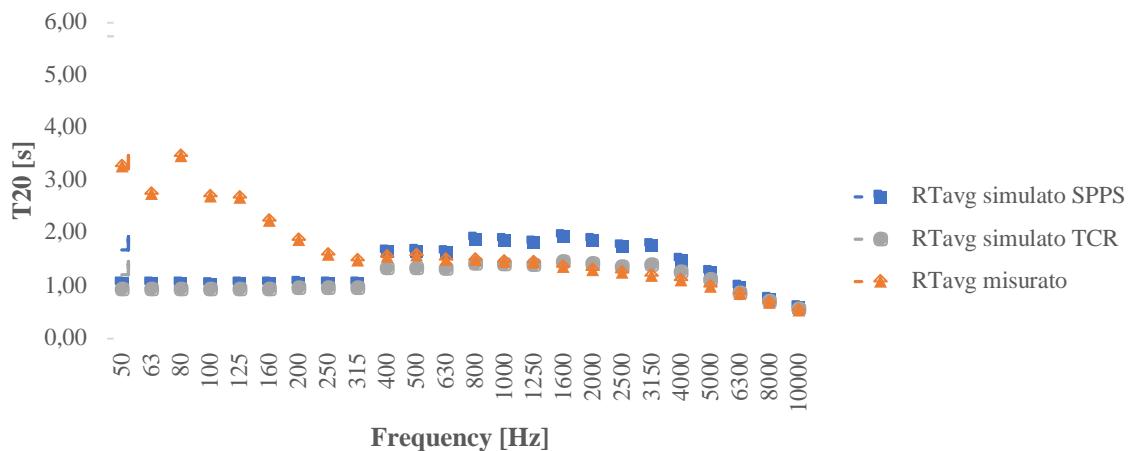
The areas concerning the surfaces to which these materials are assigned are:

Materials	m^2
Benches	47,87
Glass	16,68
Concrete block	98,3
Linoleum	29,26
Solid wood panels	3,15
Slate chalkboard	2,58

Table 5:9 Areas of materials present in M6

5.1.2.1 $\alpha_{M6,\text{lit}}$

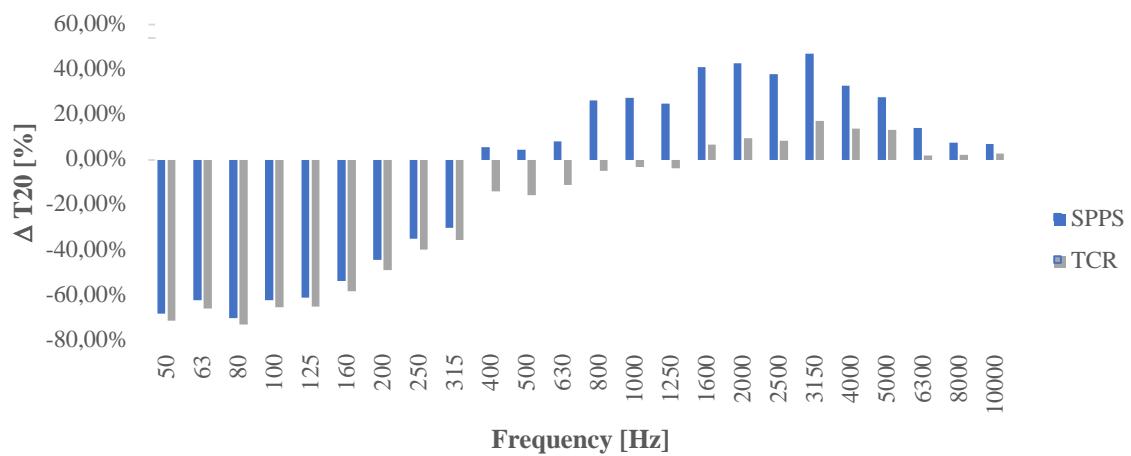
Below are the results obtained from simulations with the SPPS and TCR calculation codes by assigning to the materials the absorption coefficients reported in §5.1. All values obtained are given in Annex B.5.



Graph 5:7 T20 average values measured and simulated with material absorption coefficient not calibrated found in literature with SPPS and TCR codes

Frequency [Hz]	$\Delta T20$ [s] SPPS method	$\Delta T20$ % SPPS method	$\Delta T20$ [s] TCR method	$\Delta T20$ % TCR method
50	2,24	-68,21%	2,34	-71,25%
63	1,71	-62,01%	1,81	-65,70%
80	2,44	-70,10%	2,54	-72,87%
100	1,68	-62,06%	1,76	-65,12%
125	1,64	-61,10%	1,74	-64,86%
160	1,21	-53,76%	1,31	-58,13%
200	0,83	-44,13%	0,92	-48,73%
250	0,56	-34,79%	0,64	-39,81%
315	0,45	-30,06%	0,53	-35,40%
400	-0,09	5,67%	0,22	-13,87%
500	-0,07	4,59%	0,25	-15,62%
630	-0,13	8,33%	0,17	-11,19%
800	-0,40	26,42%	0,07	-4,75%
1000	-0,40	27,62%	0,05	-3,11%
1250	-0,36	25,01%	0,05	-3,68%
1600	-0,56	41,04%	-0,09	6,73%
2000	-0,56	42,95%	-0,13	9,60%
2500	-0,48	38,13%	-0,11	8,56%
3150	-0,57	47,19%	-0,21	17,25%
4000	-0,37	32,84%	-0,16	13,97%
5000	-0,28	27,88%	-0,13	13,39%
6300	-0,12	14,30%	-0,02	1,92%
8000	-0,05	7,71%	-0,02	2,26%
10000	-0,04	7,11%	-0,02	2,81%

Table 5:10 Values of percentage difference between T20 simulated and measured with SPPS and TCR codes with sound absorption coefficient found in literature not calibrated



Graph 5:8 Representation of values present in table 5:10

5.1.2.2 $\alpha_{M6,lit,calibrated}$

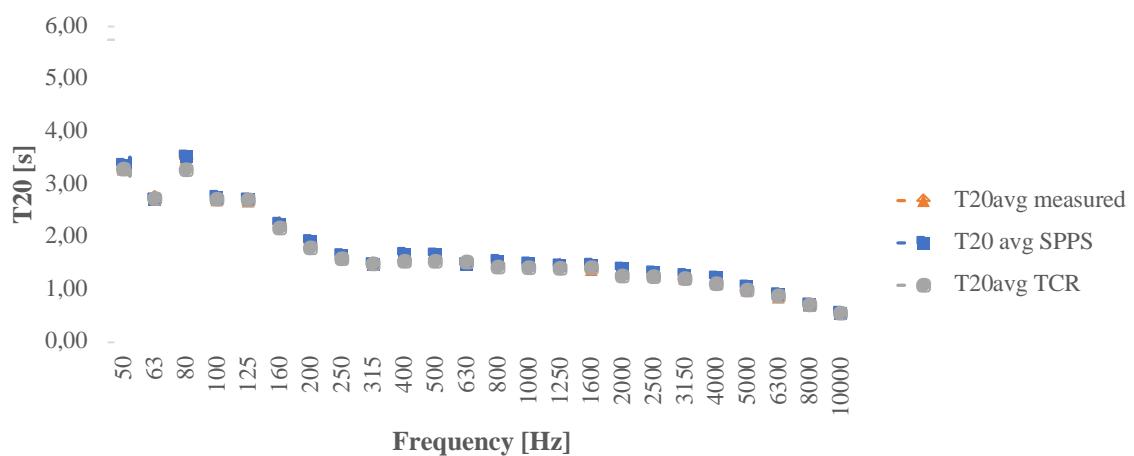
Below are the results obtained from simulations with the SPPS and TCR calculation codes by assigning to the materials the absorption coefficients calibrated. All values obtained are given in Annex B.6

Frequency [Hz]	α_{SPPS}					
	Benches	Glass	Slate chalkboard	Concrete block	linoleum	Solid wood panels
50	0,03	0,06	0,05	0,03	0,01	0,03
63	0,04	0,07	0,06	0,04	0,01	0,04
80	0,03	0,05	0,04	0,03	0,01	0,03
100	0,04	0,07	0,06	0,04	0,01	0,04
125	0,04	0,07	0,06	0,04	0,01	0,04
160	0,05	0,08	0,07	0,05	0,01	0,05
200	0,05	0,10	0,08	0,06	0,01	0,04
250	0,06	0,12	0,10	0,07	0,01	0,05
315	0,06	0,13	0,10	0,08	0,01	0,05
400	0,08	0,06	0,12	0,08	0,02	0,05
500	0,08	0,06	0,12	0,08	0,02	0,05
630	0,09	0,07	0,12	0,09	0,02	0,05
800	0,10	0,05	0,04	0,09	0,05	0,05
1000	0,10	0,05	0,04	0,09	0,05	0,05
1250	0,10	0,05	0,04	0,09	0,05	0,05
1600	0,12	0,04	0,07	0,09	0,07	0,06
2000	0,12	0,04	0,07	0,09	0,07	0,06
2500	0,12	0,04	0,07	0,09	0,07	0,06
3150	0,13	0,03	0,05	0,08	0,08	0,06
4000	0,12	0,03	0,04	0,07	0,07	0,06
5000	0,12	0,03	0,04	0,07	0,07	0,06
6300	0,10	0,03	0,06	0,06	0,13	0,05
8000	0,09	0,02	0,06	0,06	0,12	0,05
10000	0,10	0,02	0,06	0,06	0,12	0,05

Table 5:11 Values of materials sound absorption coefficient calibrated with SPPS code

Frequency [Hz]	α_{TCR}					
	Benches	Glass	Slate chalkboard	Concrete block	linoleum	Solid wood panels
50	0,03	0,05	0,04	0,03	0,01	0,03
63	0,03	0,06	0,05	0,04	0,01	0,03
80	0,03	0,05	0,04	0,03	0,01	0,03
100	0,03	0,06	0,05	0,04	0,01	0,03
125	0,03	0,06	0,05	0,04	0,01	0,03
160	0,04	0,07	0,06	0,05	0,01	0,04
200	0,05	0,09	0,08	0,06	0,01	0,04
250	0,05	0,11	0,09	0,07	0,01	0,04
315	0,06	0,12	0,10	0,07	0,01	0,04
400	0,07	0,05	0,09	0,07	0,02	0,04
500	0,07	0,05	0,09	0,07	0,02	0,04
630	0,07	0,05	0,10	0,07	0,02	0,04
800	0,08	0,04	0,03	0,07	0,04	0,04
1000	0,08	0,04	0,03	0,07	0,04	0,04
1250	0,08	0,04	0,03	0,07	0,04	0,04
1600	0,09	0,03	0,05	0,06	0,05	0,04
2000	0,09	0,03	0,06	0,07	0,06	0,04
2500	0,09	0,03	0,05	0,07	0,05	0,04
3150	0,10	0,02	0,04	0,06	0,06	0,05
4000	0,10	0,02	0,04	0,06	0,06	0,05
5000	0,10	0,02	0,04	0,06	0,06	0,05
6300	0,08	0,02	0,05	0,05	0,10	0,04
8000	0,08	0,02	0,05	0,05	0,10	0,04
10000	0,09	0,02	0,05	0,05	0,11	0,04

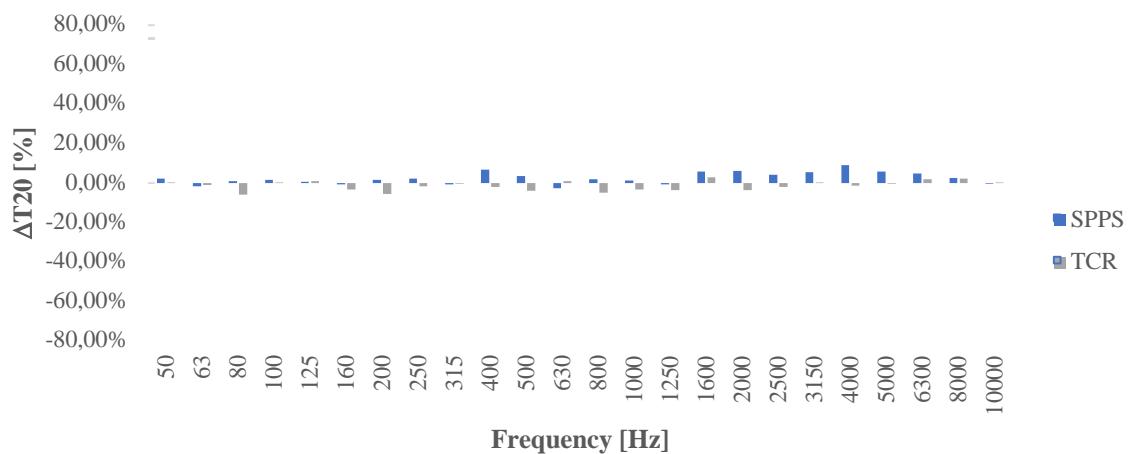
Table 5:12 Values of materials sound absorption coefficient calibrated with TCR code



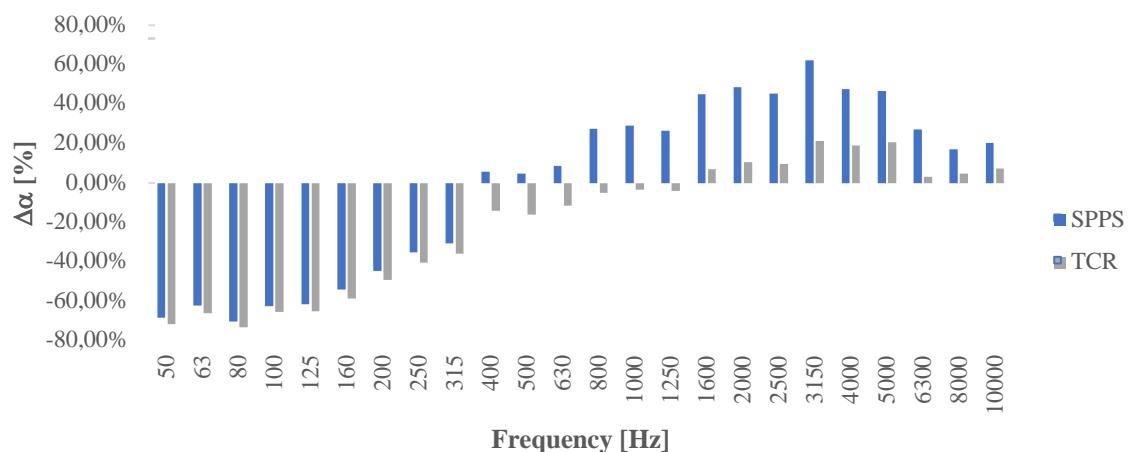
Graph 5:9 T20 average values measured and simulated with material absorption coefficient calibrated found in literature with SPPS and TCR codes

Frequency [Hz]	$\Delta T20$ [s] SPPS method	$\Delta T20$ % SPPS method	$\Delta \alpha$ [%] SPPS method	$\Delta T20$ [s] TCR method	$\Delta T20$ % TCR method	$\Delta \alpha$ [%] TCR method
50	-0,08	2,42%	-68,25%	0,00	0,04%	-71,28%
63	0,05	-1,74%	-62,07%	0,03	-1,06%	-65,75%
80	-0,04	1,05%	-70,20%	0,20	-5,80%	-72,96%
100	-0,04	1,65%	-62,18%	-0,01	0,40%	-65,25%
125	-0,02	0,75%	-61,28%	-0,03	0,99%	-65,04%
160	0,01	-0,50%	-53,99%	0,08	-3,35%	-58,36%
200	-0,03	1,51%	-44,40%	0,10	-5,39%	-49,01%
250	-0,03	2,17%	-35,07%	0,03	-1,61%	-40,11%
315	0,01	-0,78%	-30,37%	0,00	-0,15%	-35,74%
400	-0,11	6,79%	5,79%	0,03	-1,82%	-14,10%
500	-0,06	3,71%	4,71%	0,06	-3,85%	-15,93%
630	0,04	-2,48%	8,57%	-0,01	0,93%	-11,46%
800	-0,03	1,92%	27,51%	0,07	-4,75%	-4,90%
1000	-0,02	1,44%	29,03%	0,05	-3,11%	-3,23%
1250	0,01	-0,68%	26,64%	0,05	-3,68%	-3,86%
1600	-0,08	5,96%	45,00%	-0,04	2,88%	7,21%
2000	-0,08	6,13%	48,73%	0,05	-3,46%	10,56%
2500	-0,05	4,22%	45,48%	0,02	-1,92%	9,80%
3150	-0,07	5,53%	62,37%	0,00	0,06%	21,39%
4000	-0,10	8,95%	47,57%	0,02	-1,37%	19,03%
5000	-0,06	5,90%	46,63%	0,00	-0,25%	20,81%
6300	-0,04	4,78%	27,36%	-0,02	1,92%	3,34%
8000	-0,02	2,45%	17,26%	-0,02	2,26%	4,76%
10000	0,00	-0,06%	20,53%	0,00	0,49%	7,56%

Table 5:7 Values of percentage difference between T20 simulated with sound absorption coefficient found in literature calibrated and values of percentage difference between average sound absorption coefficient calibrated and measured with SPPS and TCR codes

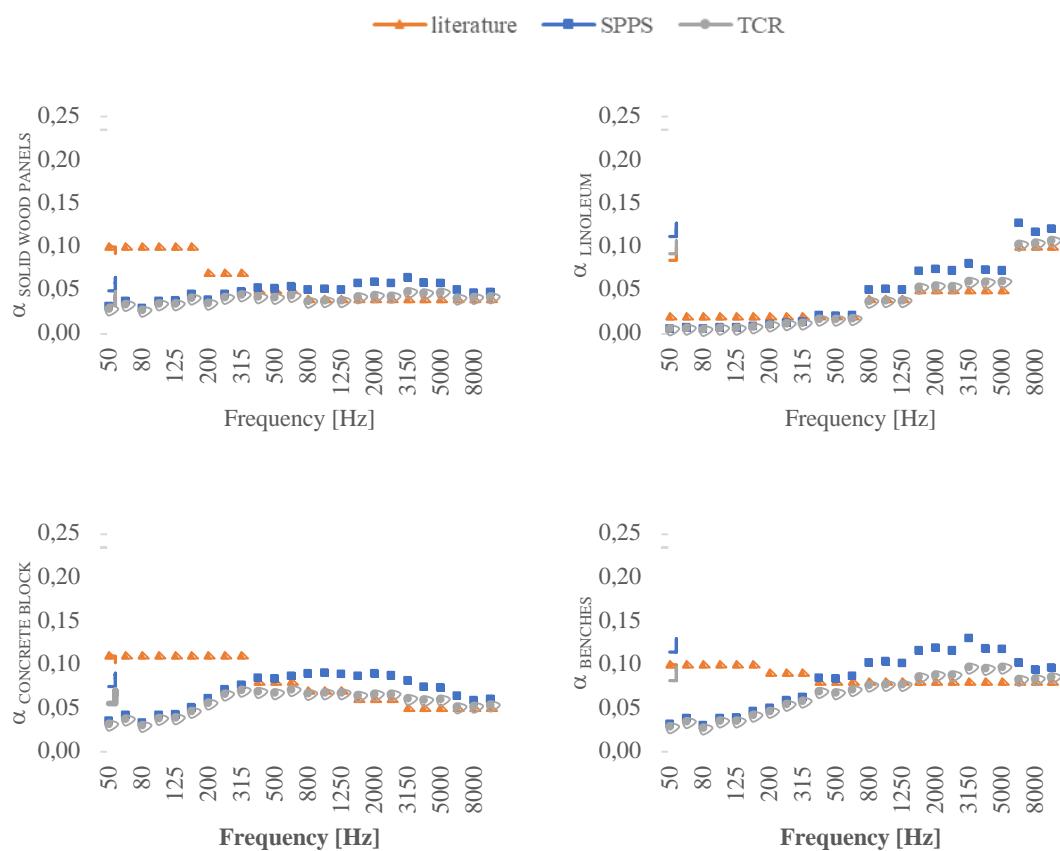


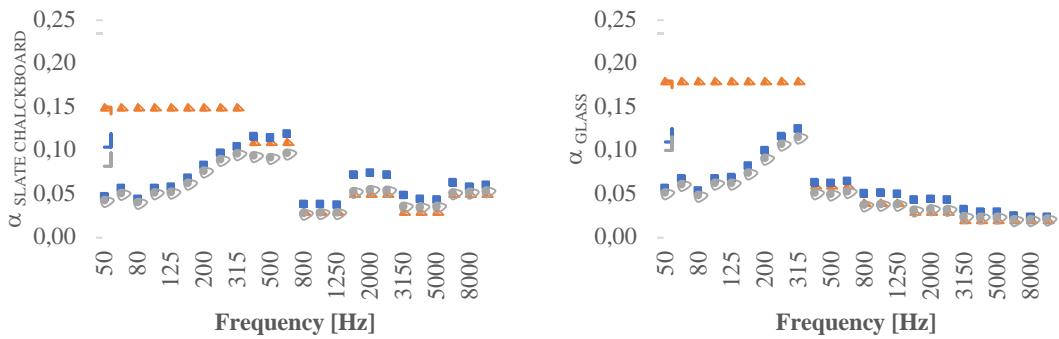
Graph 5:10 Representation of values present in table 5:7



Graph 5:11 Representation of values present in table 5:7

The values of the absorption coefficients of the materials found in the literature (table 5:3) can be reported with the corresponding values obtained from the calibration process in graphs (values of sound absorption coefficient calibrated in table 5:11 for SPPS and 5:12 for TCR), one for each material.





We can observe that at low frequencies, the coefficients found in the literature are higher than those obtained with the calibration process in order to try to obtain the measured reverberation time, as confirmed by graph 5:7 in which the trend of the measured reverberation time is represented es simulated with absorption coefficients of the material not yet calibrated. At high frequencies, however, the literature coefficients are lower than those obtained with calibration. In particular, we can observe that this change of values occurs around Schroeder's frequency which, as identified in §3.2.2.3, is 347 Hz for the M6 classroom.

5.1.3 M10

The materials that are present in M10 are:

- Benches (for furniture);
- Glass, large panels of heavy plate glass (for windows);
- Concrete block, with or without plaster, painted (for walls and ceiling);
- Linoleum (for the floor);
- Solid wood panels (for REI doors);
- Slate chalkboard;
- Solid glass blocks (for the windows on the partition between the classroom and the contingent department).

To whom are assigned the absorption coefficients present in §5.1.

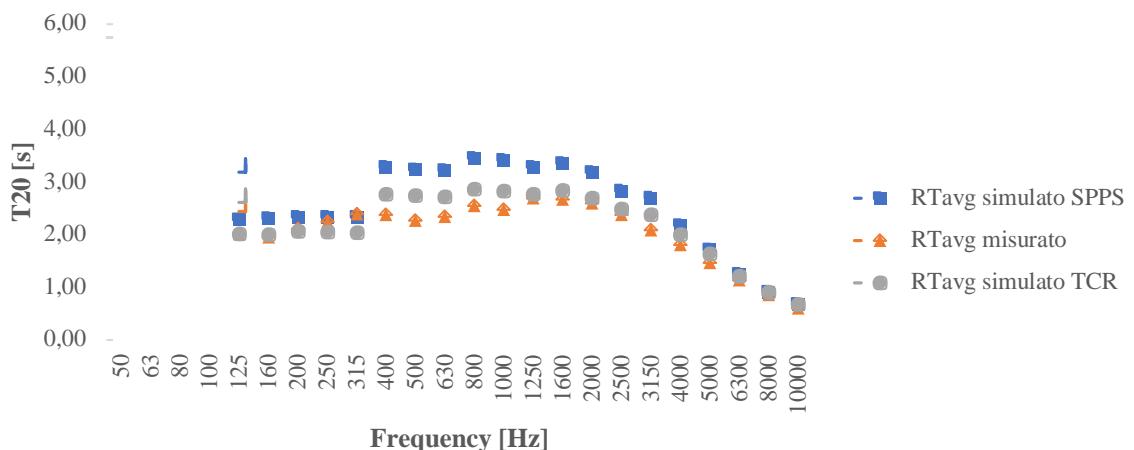
The areas concerning the surfaces to which these materials are assigned are:

Materials	m ²
Benches	276,31
Glass	68,57
Concrete block	614,87
Linoleum	147,96
Solid wood panels	20,14
Slate chalkboard	6,48
Solid glass block	13,64

Table 5:14 Ares of materials present in M10

5.1.3.1 $\alpha_{M10,lit}$

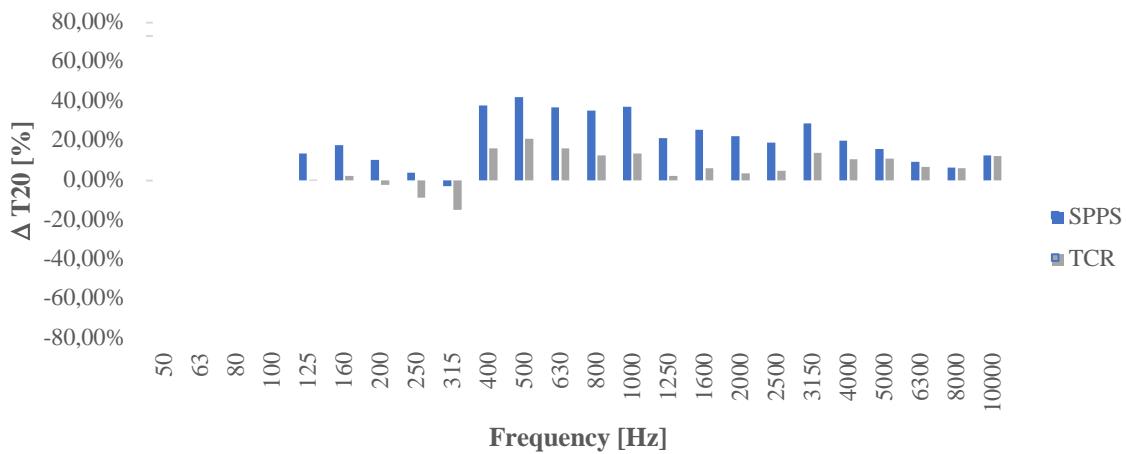
Below are the results obtained from simulations with the SPPS and TCR calculation codes by assigning to the materials the absorption coefficients reported in §5.1. All values obtained are given in Annex C.3.



Graph 5:13 T20 average values measured and simulated with material absorption coefficient not calibrated found in literature with SPPS and TCR codes

Frequency [Hz]	$\Delta T20$ [s] SPPS method	$\Delta T20$ % SPPS method	$\Delta T20$ [s] TCR method	$\Delta T20$ % TCR method
50	-	-	-	-
63	-	-	-	-
80	-	-	-	-
100	-	-	-	-
125	-0,49	13,81%	0,02	0,18%
160	-0,46	17,88%	-0,03	2,48%
200	-0,57	10,53%	-0,09	-2,30%
250	-0,46	3,90%	0,06	-8,70%
315	-0,47	-2,80%	-0,05	-14,75%
400	-0,57	38,06%	-0,05	16,30%
500	-0,60	42,31%	-0,15	21,03%
630	-0,54	37,12%	-0,06	16,20%
800	-0,53	35,46%	-0,15	12,84%
1000	-0,54	37,31%	-0,18	13,87%
1250	-0,30	21,49%	0,10	2,44%
1600	-0,48	25,65%	-0,20	6,37%
2000	-0,38	22,46%	-0,12	3,58%
2500	-0,36	19,32%	-0,14	4,84%
3150	-0,10	28,88%	0,07	14,05%
4000	-0,18	20,16%	-0,10	10,95%
5000	-0,01	16,07%	0,02	11,05%
6300	0,00	9,48%	-0,01	6,76%
8000	-0,02	6,59%	-0,02	6,22%
10000	0,01	12,67%	0,00	12,38%

Table 5:15 Values of percentage difference between T20 simulated and measured with SPPS and TCR codes with sound absorption coefficient found in literature not calibrated



Graph 5:14 Representation of values present in table 5:15

5.1.3.2 $\alpha_{M10,lit,calibrated}$

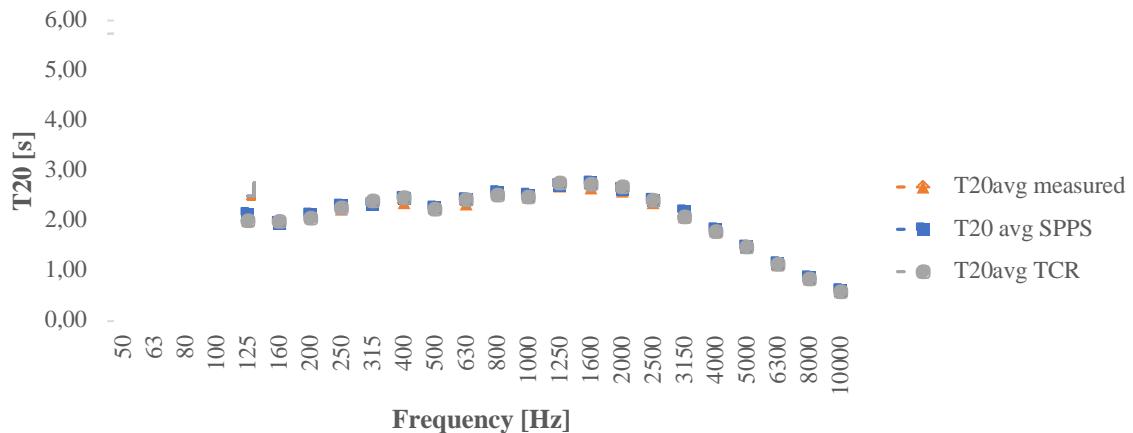
Below are the results obtained from simulations with the SPPS and TCR calculation codes by assigning to the materials the absorption coefficients calibrated. All values obtained are given in Annex C.4.

Frequency [Hz]	α_{SPPS}						
	Benches	Glass	Slate chalkboard	Concrete block	linoleum	Solid wood panels	Solid glass block
50	-	-	-	-	-	-	-
63	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-
100	-	-	-	-	-	-	-
125	0,11	0,20	0,17	0,12	0,02	0,11	0,02
160	0,12	0,21	0,18	0,13	0,02	0,12	0,02
200	0,10	0,20	0,17	0,12	0,02	0,08	0,02
250	0,09	0,19	0,16	0,11	0,02	0,07	0,02
315	0,09	0,17	0,15	0,11	0,02	0,07	0,02
400	0,11	0,08	0,15	0,11	0,03	0,07	0,03
500	0,12	0,09	0,16	0,12	0,03	0,07	0,03
630	0,11	0,08	0,15	0,11	0,03	0,07	0,03
800	0,11	0,06	0,04	0,10	0,06	0,06	0,03
1000	0,11	0,06	0,04	0,10	0,06	0,06	0,03
1250	0,10	0,05	0,04	0,09	0,05	0,05	0,02
1600	0,10	0,04	0,07	0,08	0,07	0,05	0,03
2000	0,10	0,04	0,06	0,08	0,06	0,05	0,03
2500	0,10	0,04	0,06	0,08	0,06	0,05	0,03
3150	0,12	0,03	0,04	0,07	0,07	0,06	0,03
4000	0,11	0,03	0,04	0,07	0,07	0,06	0,03
5000	0,11	0,03	0,04	0,07	0,07	0,06	0,03
6300	0,10	0,03	0,06	0,06	0,13	0,05	0,03
8000	0,10	0,02	0,06	0,06	0,12	0,05	0,02
10000	0,13	0,03	0,08	0,08	0,16	0,06	0,03

Table 5:16 Values of materials sound absorption coefficient calibrated with SPPS code

Frequency [Hz]	α_{TCR}						
	Benches	Glass	Slate chalkboard	Concrete block	linoleum	Solid wood panels	Solid glass block
50	-	-	-	-	-	-	-
63	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-
100	-	-	-	-	-	-	-
125	0,10	0,18	0,15	0,11	0,02	0,10	0,02
160	0,10	0,18	0,15	0,11	0,02	0,10	0,02
200	0,09	0,18	0,15	0,11	0,02	0,07	0,02
250	0,08	0,16	0,14	0,10	0,02	0,06	0,02
315	0,08	0,15	0,13	0,09	0,02	0,06	0,02
400	0,09	0,07	0,13	0,09	0,02	0,06	0,02
500	0,10	0,07	0,13	0,10	0,02	0,06	0,02
630	0,09	0,07	0,13	0,09	0,02	0,06	0,02
800	0,09	0,05	0,03	0,08	0,05	0,05	0,02
1000	0,09	0,05	0,03	0,08	0,05	0,05	0,02
1250	0,08	0,04	0,03	0,07	0,04	0,04	0,02
1600	0,09	0,03	0,05	0,06	0,05	0,04	0,02
2000	0,08	0,03	0,05	0,06	0,05	0,04	0,02
2500	0,09	0,03	0,05	0,06	0,05	0,04	0,02
3150	0,10	0,02	0,04	0,06	0,06	0,05	0,02
4000	0,10	0,02	0,04	0,06	0,06	0,05	0,02
5000	0,10	0,03	0,04	0,06	0,06	0,05	0,03
6300	0,09	0,02	0,06	0,06	0,12	0,05	0,02
8000	0,10	0,02	0,06	0,06	0,12	0,05	0,02
10000	0,13	0,03	0,08	0,08	0,16	0,06	0,03

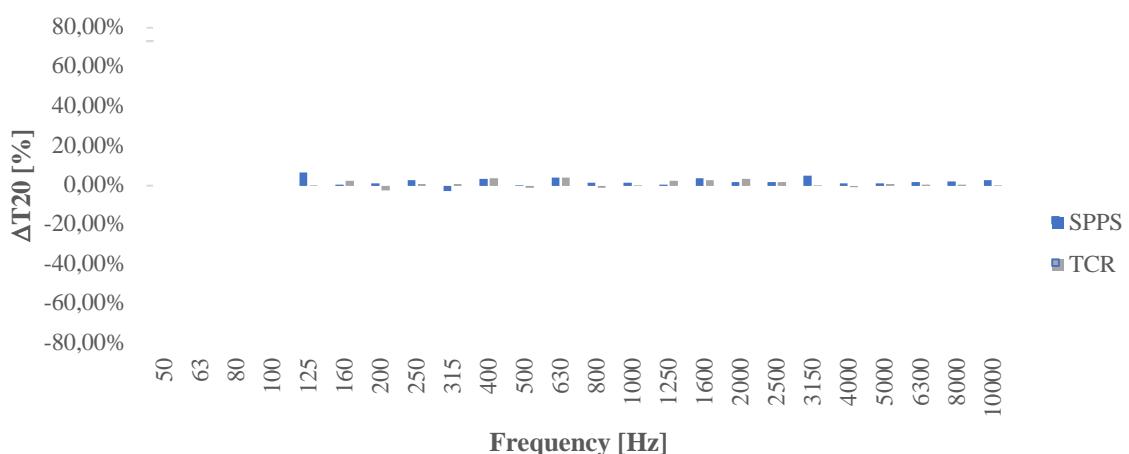
Table 5:17 Values of materials sound absorption coefficient calibrated with TCR code



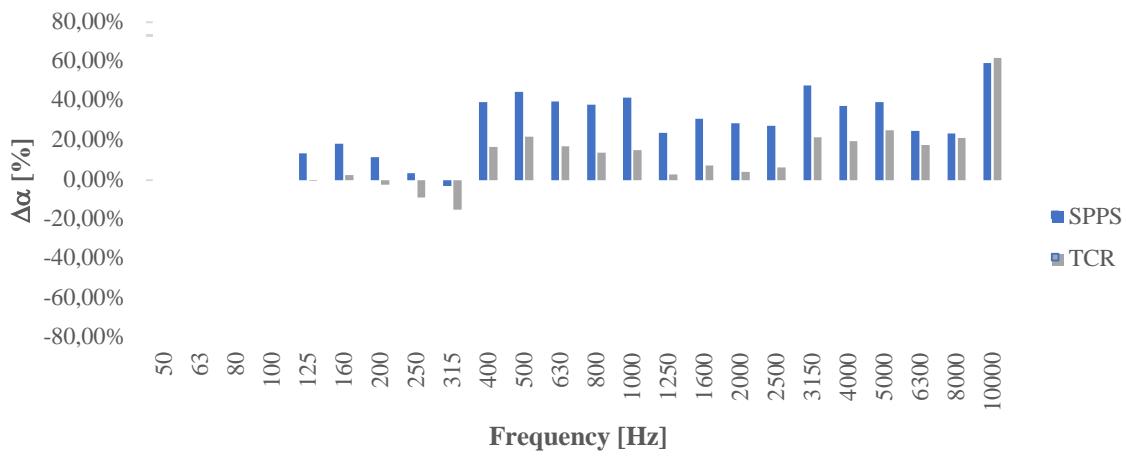
Graph 5:15 T20 average values measured and simulated with material absorption coefficient not calibrated found in literature with SPPS and TCR codes

Frequency [Hz]	ΔT_{20} [s] SPPS method	ΔT_{20} % SPPS method	$\Delta \alpha$ [%] SPPS method	ΔT_{20} [s] TCR method	ΔT_{20} % TCR method	$\Delta \alpha$ [%] TCR method
50	-	-	-	-	-	-
63	-	-	-	-	-	-
80	-	-	-	-	-	-
100	-	-	-	-	-	-
125	-0,13	6,83%	13,52%	0,01	0,18%	-0,32%
160	-0,01	0,51%	18,46%	-0,05	2,48%	2,46%
200	-0,02	1,12%	11,73%	0,05	-2,30%	-2,37%
250	-0,06	2,88%	3,48%	-0,01	0,76%	-8,96%
315	0,07	-2,80%	-2,99%	-0,02	0,83%	-15,06%
400	-0,08	3,40%	39,43%	-0,09	3,92%	16,83%
500	0,00	0,08%	44,80%	0,03	-1,16%	21,99%
630	-0,09	3,96%	39,99%	-0,09	4,00%	17,08%
800	-0,04	1,44%	38,29%	0,03	-1,06%	13,78%
1000	-0,04	1,37%	41,80%	-0,01	0,03%	15,32%
1250	-0,01	0,44%	24,08%	-0,07	2,44%	2,78%
1600	-0,10	3,64%	31,22%	-0,08	2,87%	7,36%
2000	-0,04	1,79%	28,94%	-0,09	3,58%	4,31%
2500	-0,04	1,86%	27,37%	-0,04	1,81%	6,50%
3150	-0,11	5,09%	48,07%	0,00	0,17%	21,76%
4000	-0,02	1,30%	37,59%	0,01	-0,64%	19,85%
5000	-0,02	1,06%	39,68%	-0,01	0,88%	25,36%
6300	-0,02	1,69%	25,03%	0,00	0,36%	17,85%
8000	-0,02	2,21%	23,52%	0,00	0,37%	21,35%
10000	-0,02	2,85%	59,41%	0,00	0,02%	61,81%

Table 5:18 Values of percentage difference between T_{20} simulated with sound absorption coefficient found in literature calibrated and values of percentage difference between average sound absorption coefficient calibrated and measured with SPPS and TCR codes

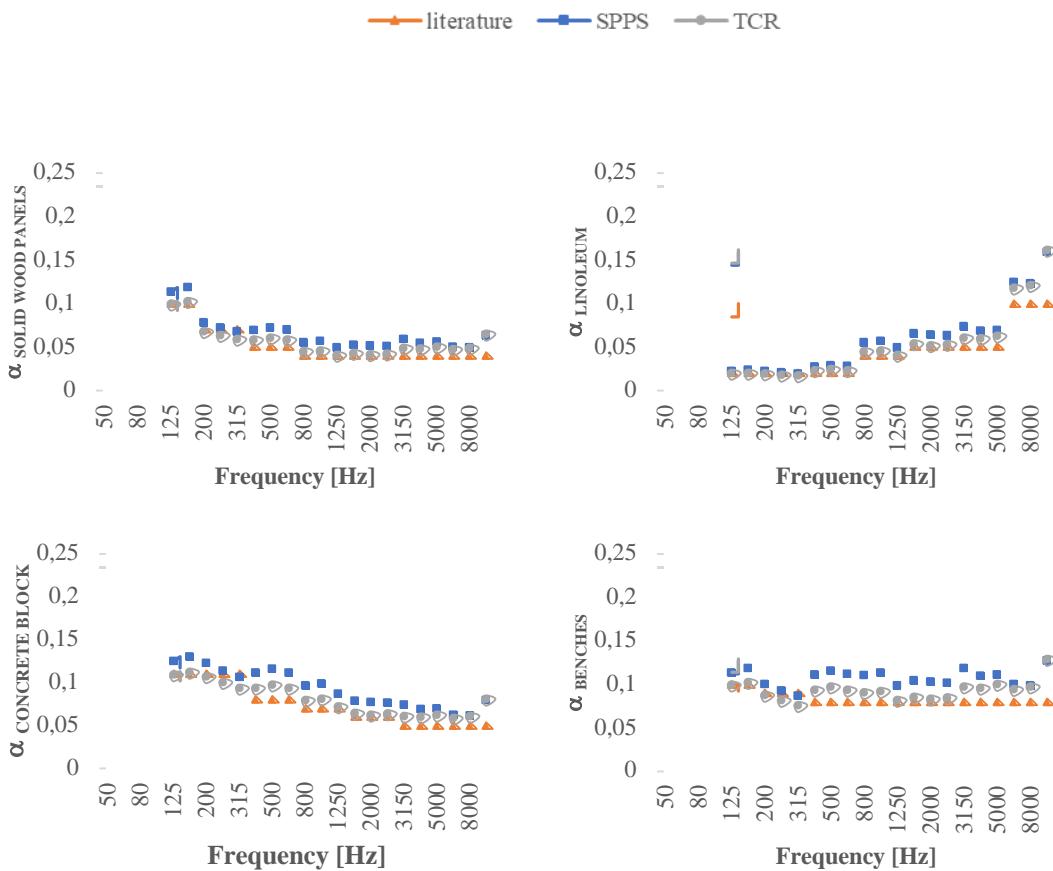


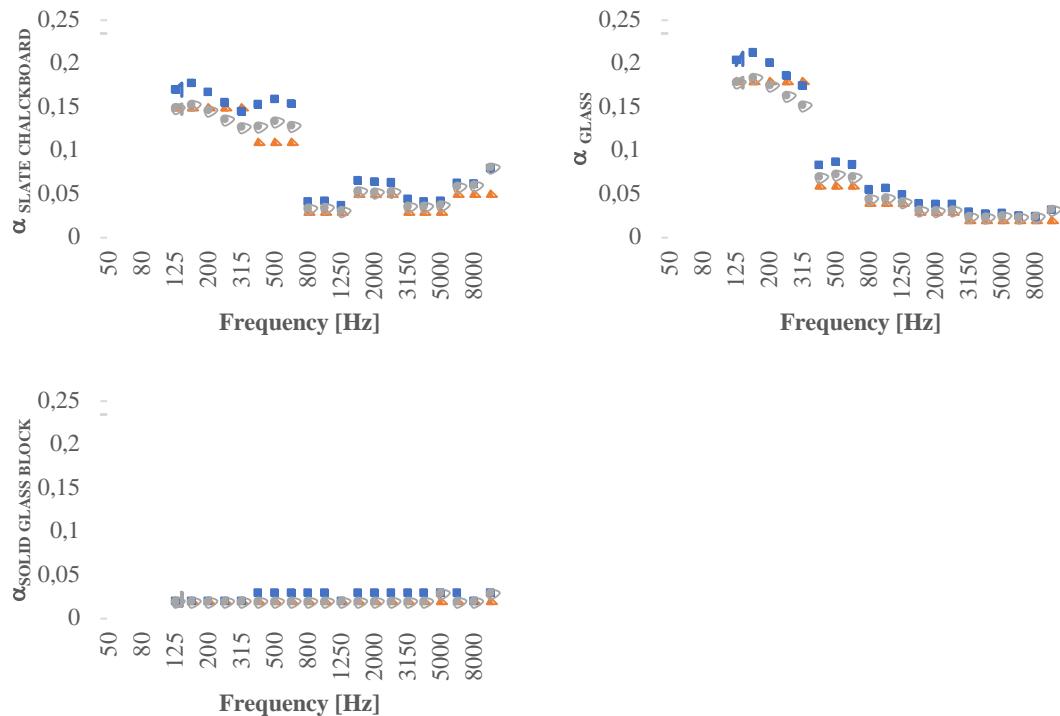
Graph 5:16 Representation of values present in table 5:18



Graph 5:17 Representation of values present in table 5:18

The values of the absorption coefficients of the materials found in the literature (table 5:3) can be reported with the corresponding values obtained from the calibration process in graphs (values of sound absorption coefficient calibrated in table 5:16 for SPPS and 5:17 for TCR), one for each material.





We can observe that all the absorption coefficients of the materials found in the literature are lower than those obtained by calibration, remember that for M10 Schroeder's frequency is 87 Hz. Therefore, not having measured values below 125 Hz and therefore below Schroeder's frequency, we do not observe, as in the case of M5 and M6, the difference in values between low and high frequencies.

5.2 $\alpha_{average}$

The values obtained from the simulations are reported considering the environments consisting of a single material with absorption coefficient obtained from the average measured reverberation time and the respective values obtained from the calibration of the model with the SPPS and TCR codes of the three classrooms under study.

5.2.1 M5

5.2.1.1 α_{M5AVG}

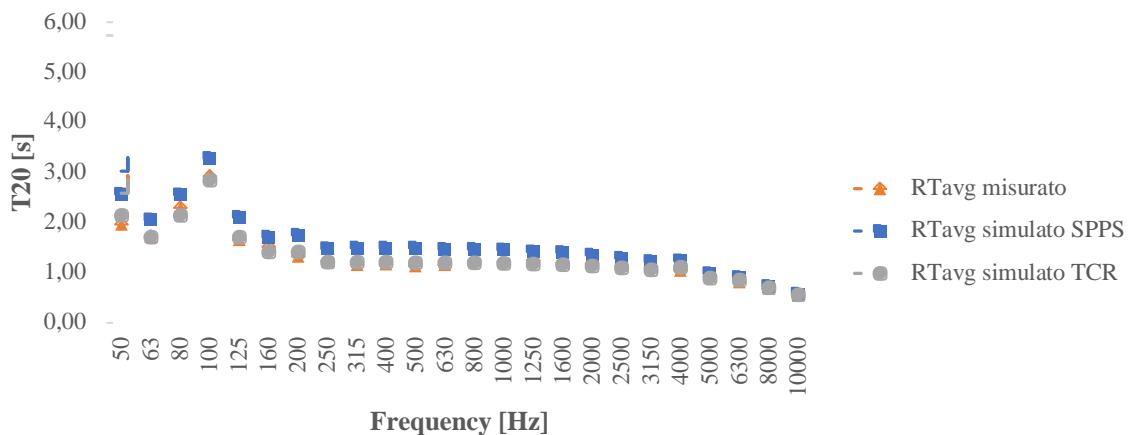
The values of the average absorption coefficient assigned to the first simulation, obtained from the average of the measured reverberation times, are shown in Table 5:19.

Frequency [Hz]	α_{M5avg}
50	0,04
63	0,05
80	0,04
100	0,03
125	0,05
160	0,06
200	0,06
250	0,07
315	0,07
400	0,07
500	0,07
630	0,07
800	0,07
1000	0,07
1250	0,07
1600	0,07
2000	0,07
2500	0,07
3150	0,07
4000	0,06
5000	0,07
6300	0,06
8000	0,06
10000	0,06

Table 5:19 Average sound absorption coefficient values

Below are the results obtained from simulations with the SPPS and TCR calculation codes by assigning to the materials the absorption coefficient.

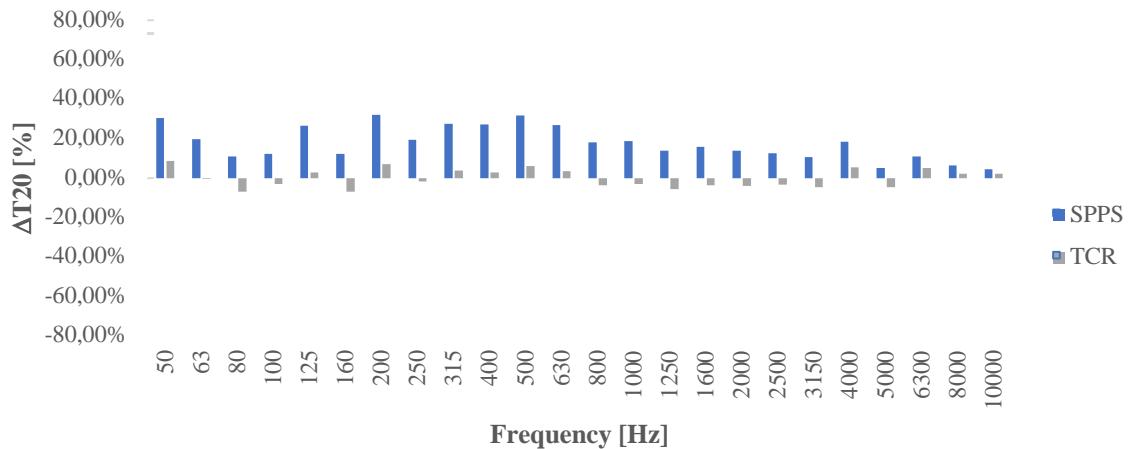
All values obtained are given in Annex A.6.



Graph 5:19 T20 average values measured and simulated with material absorption coefficient average not calibrated with SPPS and TCR codes

Frequency [Hz]	$\Delta T20$ [s] SPPS method	$\Delta T20$ % SPPS method	$\Delta T20$ [s] TCR method	$\Delta T20$ % TCR method
50	-0,60	30,38%	-0,17	8,80%
63	-0,34	19,70%	0,01	-0,44%
80	-0,25	10,98%	0,15	-6,73%
100	-0,36	12,20%	0,08	-2,81%
125	-0,44	26,44%	-0,05	2,74%
160	-0,19	12,43%	0,10	-6,70%
200	-0,43	31,99%	-0,09	6,98%
250	-0,24	19,54%	0,02	-1,69%
315	-0,32	27,47%	-0,04	3,70%
400	-0,32	27,17%	-0,03	2,90%
500	-0,36	31,74%	-0,07	6,06%
630	-0,31	27,02%	-0,04	3,43%
800	-0,22	18,07%	0,04	-3,58%
1000	-0,23	18,72%	0,04	-3,09%
1250	-0,17	13,84%	0,07	-5,50%
1600	-0,19	15,88%	0,05	-3,75%
2000	-0,17	14,05%	0,05	-4,06%
2500	-0,15	12,72%	0,04	-3,44%
3150	-0,12	10,63%	0,05	-4,59%
4000	-0,19	18,46%	-0,06	5,52%
5000	-0,05	5,24%	0,04	-4,53%
6300	-0,09	11,10%	-0,04	5,20%
8000	-0,05	6,60%	-0,02	2,31%
10000	-0,03	4,59%	-0,01	2,36%

Table 5:20 Values of percentage difference between T20 simulated and measured with SPPS and TCR codes with average sound absorption coefficient not calibrated



Graph 5:20 Representation of values present in table 5:20

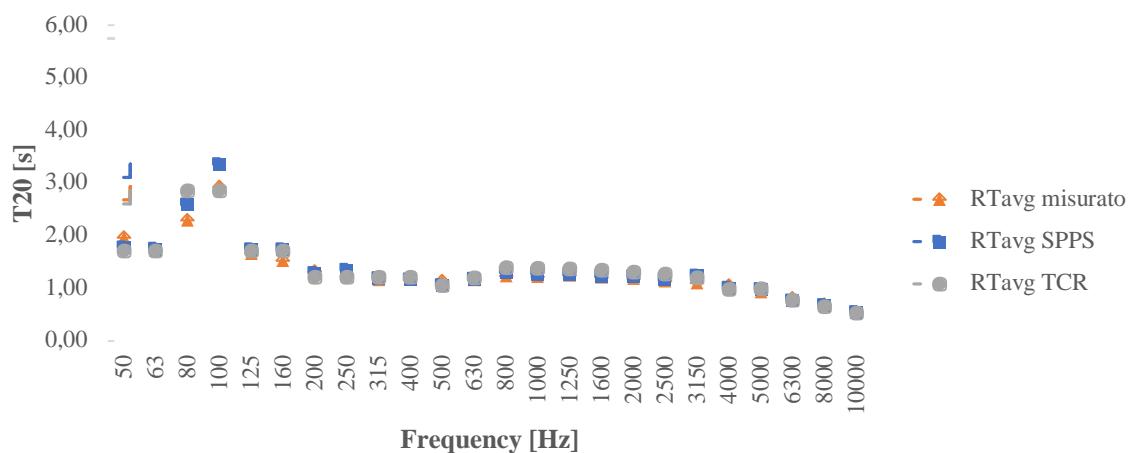
5.2.1.2 α_{M5} avg calibrated

The values of the absorption coefficients of the materials obtained from the calibration for the SPPS and TCR codes and the corresponding results in terms of reverberation time and relative percentage difference with the measured values are reported.

All values obtained are given in Annex A.7.

Frequency [Hz]	α SPPS	$\Delta\alpha [\%]$ SPPS	α TCR	$\Delta\alpha [\%]$ TCR
50	0,06	30,74%	0,05	8,81%
63	0,06	19,18%	0,05	-0,44%
80	0,04	10,40%	0,03	-6,75%
100	0,03	12,14%	0,03	-2,82%
125	0,06	26,83%	0,05	2,75%
160	0,06	12,10%	0,05	-6,74%
200	0,08	32,15%	0,07	7,04%
250	0,08	20,21%	0,07	-1,71%
315	0,09	28,30%	0,07	3,75%
400	0,09	28,87%	0,07	2,94%
500	0,10	31,89%	0,08	6,17%
630	0,09	27,58%	0,07	3,51%
800	0,08	18,29%	0,06	-3,67%
1000	0,08	19,53%	0,06	-3,19%
1250	0,08	15,14%	0,06	-5,72%
1600	0,08	17,37%	0,06	-3,96%
2000	0,08	15,24%	0,06	-4,37%
2500	0,08	13,96%	0,06	-3,82%
3150	0,07	13,36%	0,06	-5,33%
4000	0,08	24,51%	0,07	7,08%
5000	0,07	7,48%	0,06	-6,21%
6300	0,08	18,98%	0,07	8,63%
8000	0,07	14,71%	0,07	4,60%
10000	0,07	14,20%	0,07	5,93%

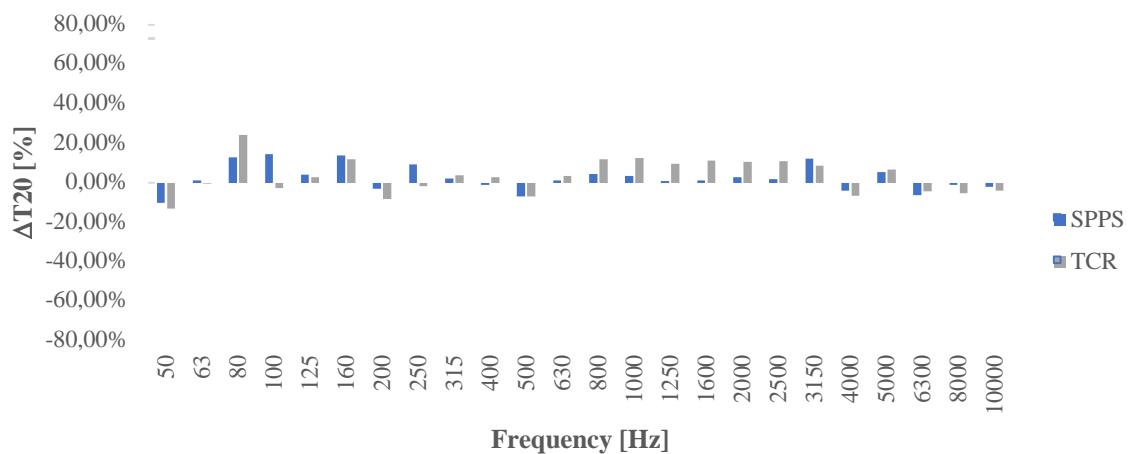
Table 5:21 Values of sound absorption coefficient calibrated and percentage difference between average sound absorption coefficient simulated and measured with SPPS and TCR codes



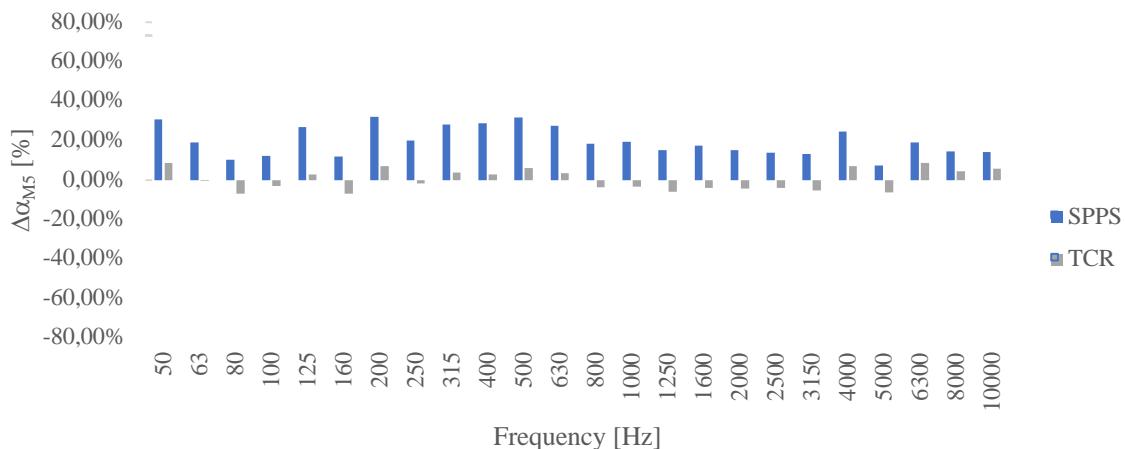
Graph 5:21 T20 average values measured and simulated with material average absorption coefficient calibrated with SPPS and TCR codes

Frequency [Hz]	$\Delta T20$ [s] SPPS method	$\Delta T20$ % SPPS method	$\Delta T20$ [s] TCR method	$\Delta T20$ % TCR method
50	0,18	-10,04%	0,26	-12,94%
63	-0,03	1,16%	0,01	-0,44%
80	-0,31	12,80%	-0,56	24,24%
100	-0,41	14,49%	0,08	-2,81%
125	-0,07	4,07%	-0,05	2,74%
160	-0,20	13,81%	-0,18	11,83%
200	0,05	-2,97%	0,11	-8,20%
250	-0,11	9,24%	0,02	-1,69%
315	-0,02	2,02%	-0,04	3,70%
400	0,03	-0,99%	-0,03	2,90%
500	0,08	-6,87%	0,08	-7,00%
630	0,01	1,31%	-0,04	3,43%
800	-0,05	4,37%	-0,15	12,02%
1000	-0,03	3,41%	-0,15	12,49%
1250	-0,01	0,94%	-0,12	9,55%
1600	-0,01	1,24%	-0,14	11,32%
2000	-0,03	2,67%	-0,13	10,63%
2500	-0,02	1,98%	-0,12	10,83%
3150	-0,11	12,10%	-0,10	8,79%
4000	0,05	-4,03%	0,07	-6,56%
5000	-0,05	5,47%	-0,06	6,56%
6300	0,05	-6,18%	0,04	-4,36%
8000	0,01	-0,91%	0,04	-5,43%
10000	0,01	-1,89%	0,02	-3,94%

Table 5:22 Values of percentage difference between T20 simulated and measured with SPPS and TCR codes with average sound absorption coefficient calibrated

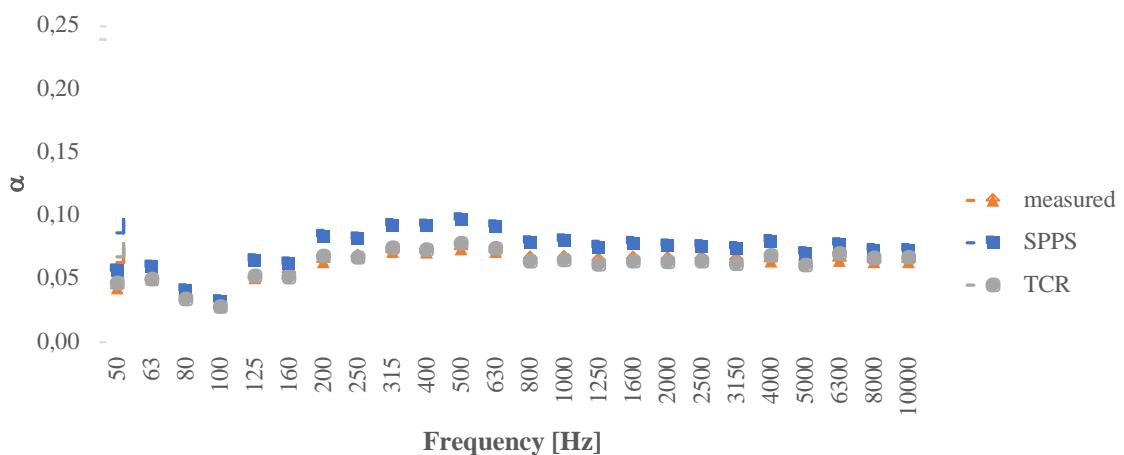


Graph 5:22 Representation of values present in table 5:22



Graph 5:23 Representation of values present in table 5:21

We therefore summarize in a single graph the trend of the absorption coefficient of the material measured and calibrated according to the two calculation codes proposed by I-Simpa.



Graph 5:24 Representation of sound absorption coefficient not calibrated and calibrated with SPPS and TCR codes from the values of table 5:21 and 5:19

From graph 5:24, the measured absorption coefficient values are lower than those found with the SPPS code calibration. Instead it is very similar to the values obtained by calibration with the TCR code. However, this does not imply an equality in terms of reverberation time as there is always a difference between the measured and simulated reverberation times.

5.2.2 M6

5.2.2.1 α_{M6AVG}

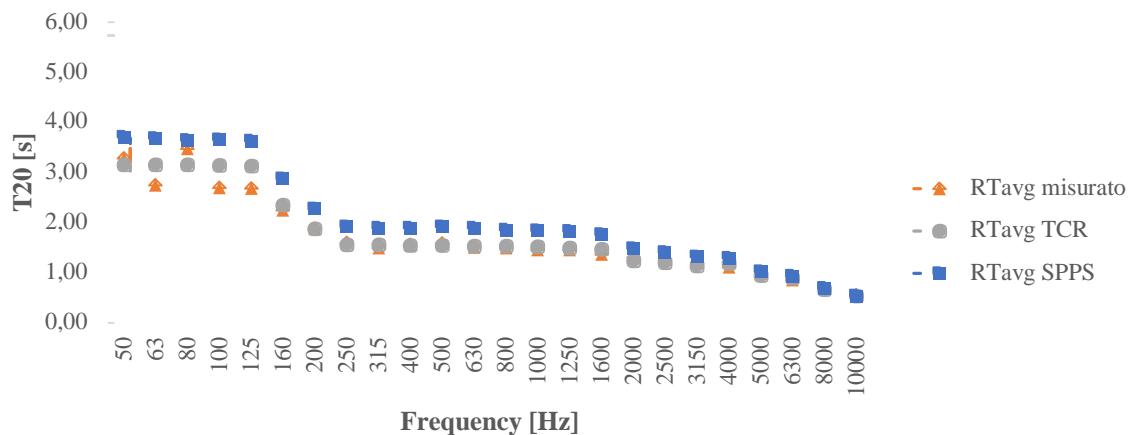
The values of the average absorption coefficient assigned to the first simulation, obtained from the average of the measured reverberation times, are shown in Table 5:23.

Frequency [Hz]	α
50	0,03
63	0,03
80	0,03
100	0,03
125	0,03
160	0,04
200	0,05
250	0,06
315	0,06
400	0,06
500	0,06
630	0,06
800	0,06
1000	0,06
1250	0,06
1600	0,06
2000	0,07
2500	0,07
3150	0,07
4000	0,06
5000	0,07
6300	0,06
8000	0,07
10000	0,07

Table 5:23 Average sound absorption coefficient values

Below are the results obtained from simulations with the SPPS and TCR calculation codes by assigning to the materials the absorption coefficient.

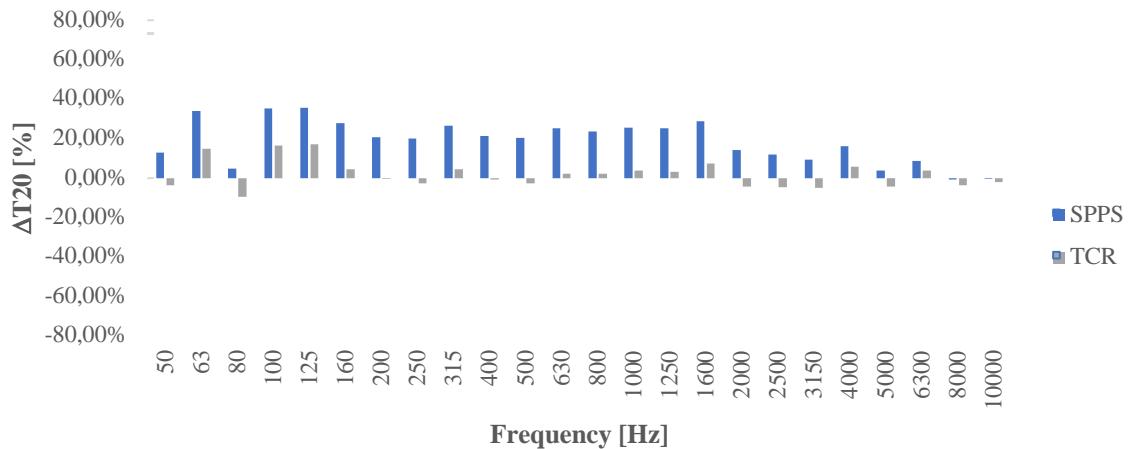
All values obtained are given in Annex B.7.



Graph 5:25 T20 average values measured and simulated with material absorption coefficient average not calibrated with SPPS and TCR codes

Frequency [Hz]	$\Delta T20$ [s] SPPS method	$\Delta T20$ % SPPS method	$\Delta T20$ [s] TCR method	$\Delta T20$ % TCR method
50	-0,42	12,89%	0,12	-3,76%
63	-0,94	34,01%	-0,41	14,73%
80	-0,17	4,84%	0,33	-9,36%
100	-0,95	35,24%	-0,44	16,36%
125	-0,95	35,52%	-0,46	17,00%
160	-0,62	27,79%	-0,10	4,60%
200	-0,39	20,81%	0,01	-0,42%
250	-0,32	19,92%	0,04	-2,51%
315	-0,40	26,70%	-0,07	4,50%
400	-0,33	21,24%	0,01	-0,69%
500	-0,33	20,54%	0,04	-2,75%
630	-0,38	25,28%	-0,03	2,29%
800	-0,36	23,80%	-0,03	2,10%
1000	-0,38	25,60%	-0,06	3,80%
1250	-0,37	25,12%	-0,05	3,11%
1600	-0,40	28,80%	-0,10	7,36%
2000	-0,19	14,35%	0,06	-4,25%
2500	-0,15	11,84%	0,06	-4,70%
3150	-0,11	9,39%	0,06	-4,89%
4000	-0,18	16,09%	-0,07	5,88%
5000	-0,04	3,86%	0,04	-4,34%
6300	-0,07	8,71%	-0,03	3,80%
8000	0,00	-0,56%	0,02	-3,54%
10000	0,00	-0,48%	0,01	-1,87%

Table 5:24 Values of percentage difference between T20 simulated and measured with SPPS and TCR codes with average sound absorption coefficient not calibrated



Graph 5:26 Representation of values present in table 5:24

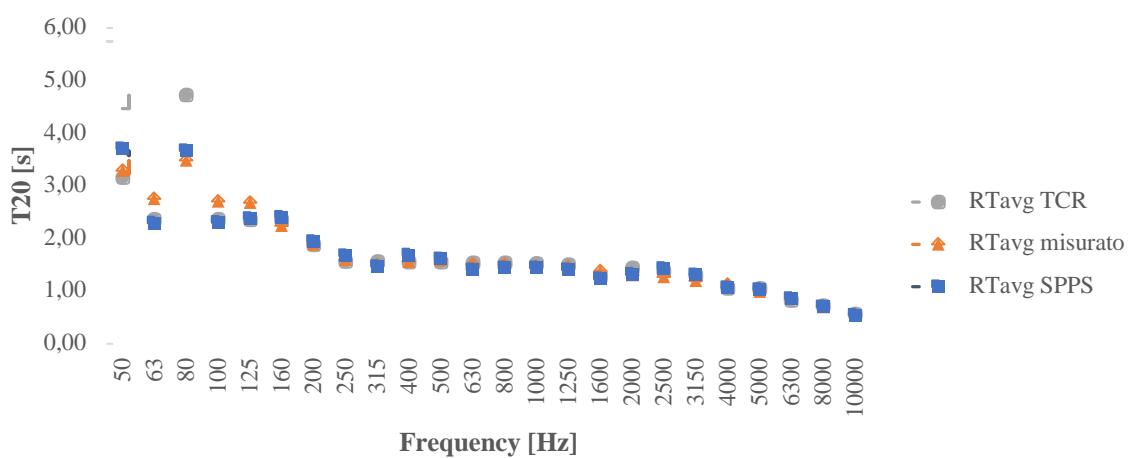
5.2.2.2 α_{M6} avg calibrated

The values of the absorption coefficients of the materials obtained from the calibration for the SPPS and TCR codes and the corresponding results in terms of reverberation time and relative percentage difference with the measured values are reported.

All values obtained are given in Annex B.8.

Frequency [Hz]	α SPPS	$\Delta\alpha [\%]$ SPPS	α TCR	$\Delta\alpha [\%]$ TCR
50	0,03	12,87%	0,03	-3,76%
63	0,05	33,70%	0,04	14,77%
80	0,03	4,31%	0,02	-9,40%
100	0,05	35,52%	0,04	16,47%
125	0,05	36,14%	0,04	17,16%
160	0,05	27,76%	0,04	4,64%
200	0,06	21,84%	0,05	-0,42%
250	0,07	19,32%	0,06	-2,54%
315	0,08	26,35%	0,06	4,57%
400	0,07	21,36%	0,06	-0,70%
500	0,07	20,35%	0,06	-2,82%
630	0,08	27,43%	0,06	2,35%
800	0,08	25,20%	0,06	2,16%
1000	0,08	26,89%	0,06	3,95%
1250	0,08	26,90%	0,06	3,28%
1600	0,09	33,14%	0,07	7,89%
2000	0,08	16,91%	0,06	-4,62%
2500	0,07	13,95%	0,06	-5,29%
3150	0,07	10,53%	0,06	-5,81%
4000	0,08	22,41%	0,07	7,81%
5000	0,07	5,83%	0,06	-6,21%
6300	0,07	15,48%	0,07	6,70%
8000	0,07	-1,23%	0,06	-7,01%
10000	0,07	-0,62%	0,06	-4,67%

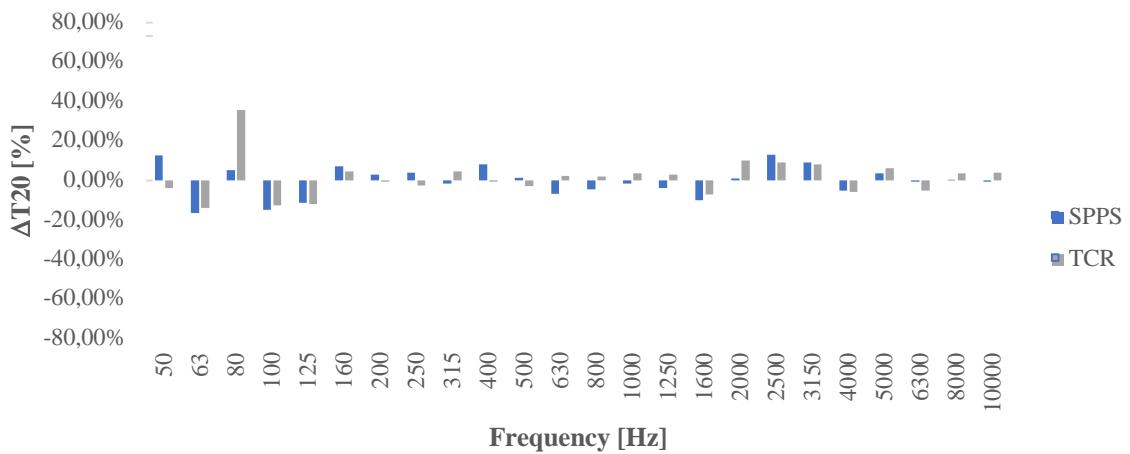
Table 5:25 Values of sound absorption coefficient calibrated and percentage difference between average sound absorption coefficient simulated and measured with SPPS and TCR codes



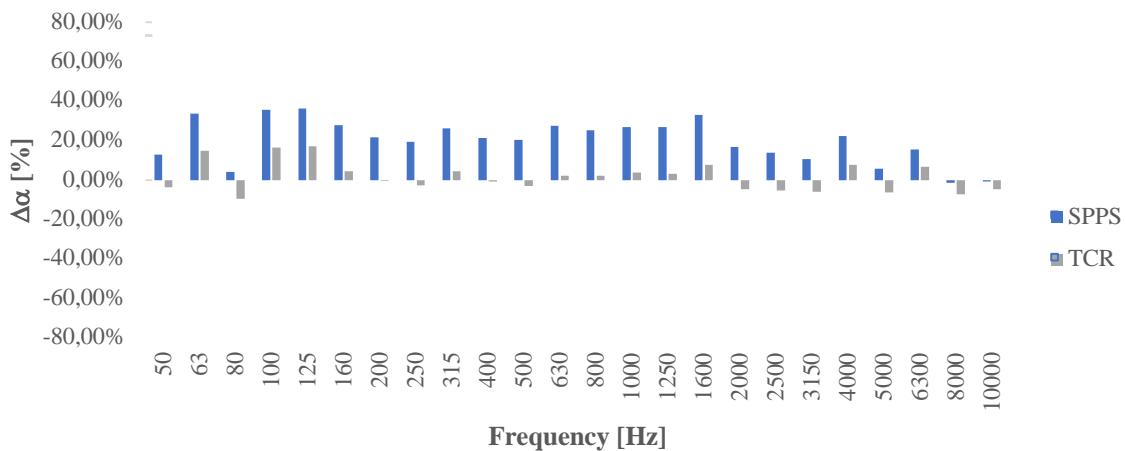
Graph 5:27 T20 average values measured and simulated with material average absorption coefficient calibrated with SPPS and TCR codes

Frequency [Hz]	$\Delta T20$ [s] SPPS method	$\Delta T20$ % SPPS method	$\Delta T20$ [s] TCR method	$\Delta T20$ % TCR method
50	-0,42	12,64%	0,12	-3,76%
63	0,46	-16,58%	0,38	-13,89%
80	-0,18	5,22%	-1,24	35,67%
100	0,40	-14,95%	0,34	-12,59%
125	0,30	-11,30%	0,32	-12,05%
160	-0,16	7,09%	-0,10	4,60%
200	-0,05	2,88%	0,01	-0,42%
250	-0,06	3,94%	0,04	-2,51%
315	0,02	-1,54%	-0,07	4,50%
400	-0,13	8,05%	0,01	-0,69%
500	-0,02	1,52%	0,04	-2,75%
630	0,10	-6,77%	-0,03	2,29%
800	0,06	-4,30%	-0,03	2,10%
1000	0,02	-1,57%	-0,06	3,80%
1250	0,06	-3,82%	-0,05	3,11%
1600	0,14	-9,88%	0,10	-7,07%
2000	-0,02	1,16%	-0,13	10,24%
2500	-0,17	13,13%	-0,12	9,16%
3150	-0,11	9,11%	-0,10	8,12%
4000	0,06	-4,94%	0,07	-5,87%
5000	-0,04	3,62%	-0,06	6,25%
6300	0,00	-0,54%	0,04	-5,12%
8000	0,00	0,48%	-0,03	3,79%
10000	0,00	-0,64%	-0,02	4,03%

Table 5:26 Values of percentage difference between T20 simulated and measured with SPPS and TCR codes with average sound absorption coefficient calibrated

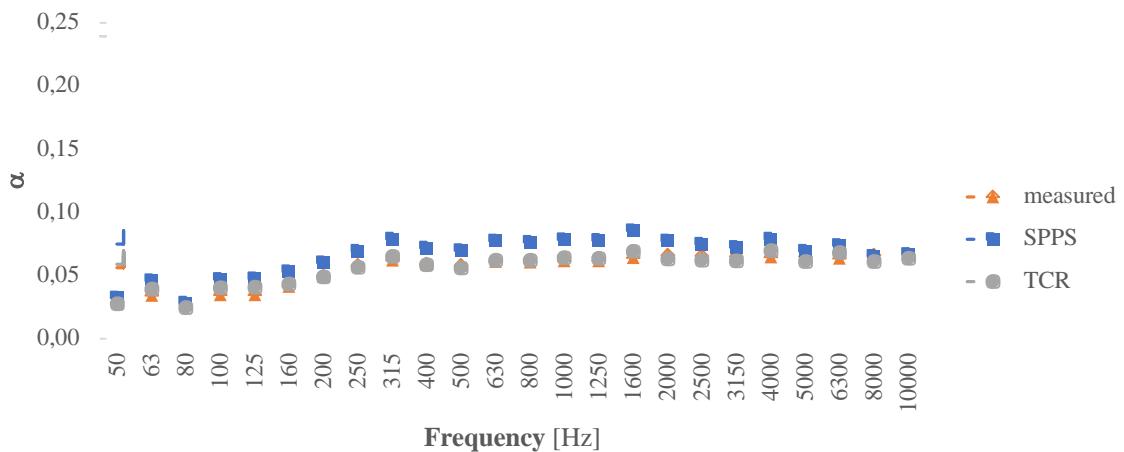


Graph 5:28 Representation of values present in table 5:26



Graph 5:29 Representation of values present in table 5:25

We therefore summarize in a single graph the trend of the absorption coefficient of the material measured and calibrated according to the two calculation codes proposed by I-Simpa.



Graph 5:30 Representation of sound absorption coefficient not calibrated and calibrated with SPPS and TCR codes from the values in table 5:23 and 5:25

From graph 5:30, the measured absorption coefficient values are lower than those found with the SPPS code calibration. Instead it is very similar to the values obtained by calibration with the TCR code. However, this does not imply an equality in terms of reverberation time as there is always a difference between the measured and simulated reverberation times.

5.2.3 M10

5.2.3.1 α_{M10AVG}

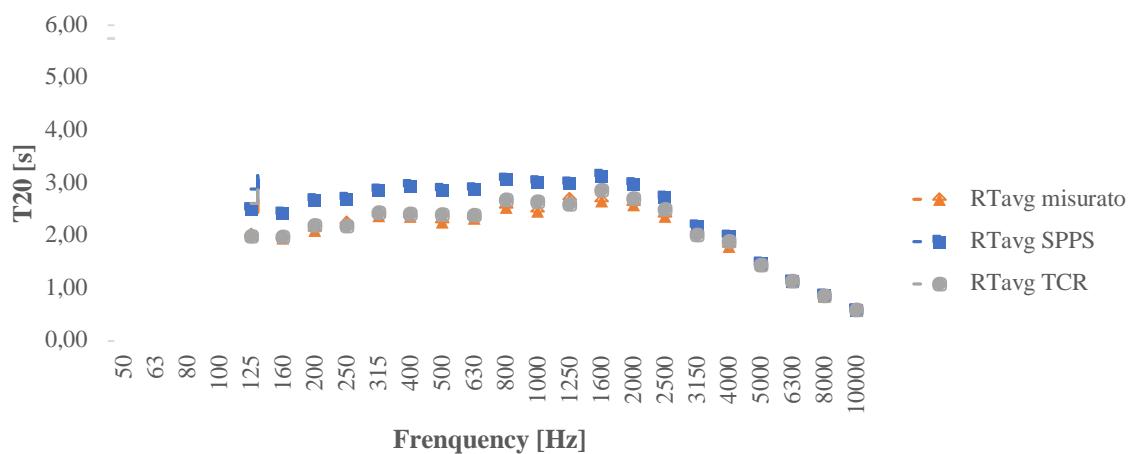
The values of the average absorption coefficient assigned to the first simulation, obtained from the average of the measured reverberation times, are shown in Table 5:27.

Frequency [Hz]	α
50	-
63	-
80	-
100	-
125	0,10
160	0,10
200	0,09
250	0,09
315	0,08
400	0,08
500	0,08
630	0,08
800	0,07
1000	0,07
1250	0,07
1600	0,06
2000	0,06
2500	0,06
3150	0,07
4000	0,06
5000	0,07
6300	0,07
8000	0,07
10000	0,10

Table 5:27 Average sound absorption coefficient values

Below are the results obtained from simulations with the SPPS and TCR calculation codes by assigning to the materials the absorption coefficient.

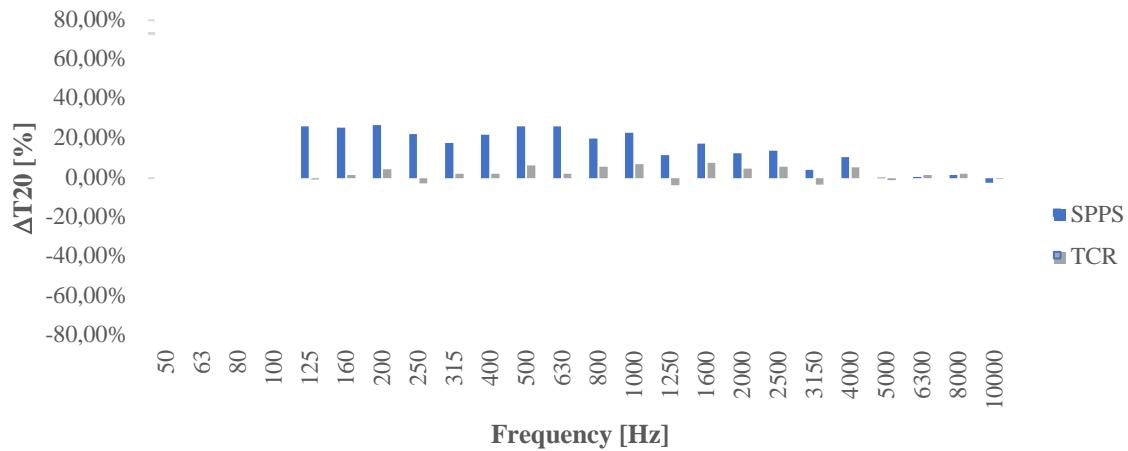
All values obtained are given in the Annex C.5.



Graph 5:31 T20 average values measured and simulated with material absorption coefficient average not calibrated with SPPS and TCR codes

Frequency [Hz]	$\Delta T20$ [s] SPPS method	$\Delta T20$ % SPPS method	$\Delta T20$ [s] TCR method	$\Delta T20$ % TCR method
50	-	-	-	-
63	-	-	-	-
80	-	-	-	-
100	-	-	-	-
125	-0,49	26,14%	0,02	-0,64%
160	-0,46	25,73%	-0,03	1,64%
200	-0,57	26,73%	-0,09	4,39%
250	-0,46	22,49%	0,06	-2,48%
315	-0,47	17,95%	-0,05	2,11%
400	-0,57	22,00%	-0,05	2,25%
500	-0,60	26,32%	-0,15	6,50%
630	-0,54	26,12%	-0,06	2,35%
800	-0,53	19,93%	-0,15	5,89%
1000	-0,54	23,03%	-0,18	6,96%
1250	-0,30	11,65%	0,10	-3,65%
1600	-0,48	17,38%	-0,20	7,66%
2000	-0,38	12,48%	-0,12	4,77%
2500	-0,36	13,80%	-0,14	5,96%
3150	-0,10	4,09%	0,07	-3,39%
4000	-0,18	10,56%	-0,10	5,45%
5000	-0,01	0,35%	0,02	-1,17%
6300	0,00	0,66%	-0,01	1,45%
8000	-0,02	1,71%	-0,02	2,24%
10000	0,01	-2,28%	0,00	-0,46%

Table 5:28 Values of sound absorption coefficient calibrated and percentage difference between T20 simulated and measured with SPPS and TCR codes with average sound absorption coefficient not calibrated



Graph 5:32 Representation of values present in table 5:31

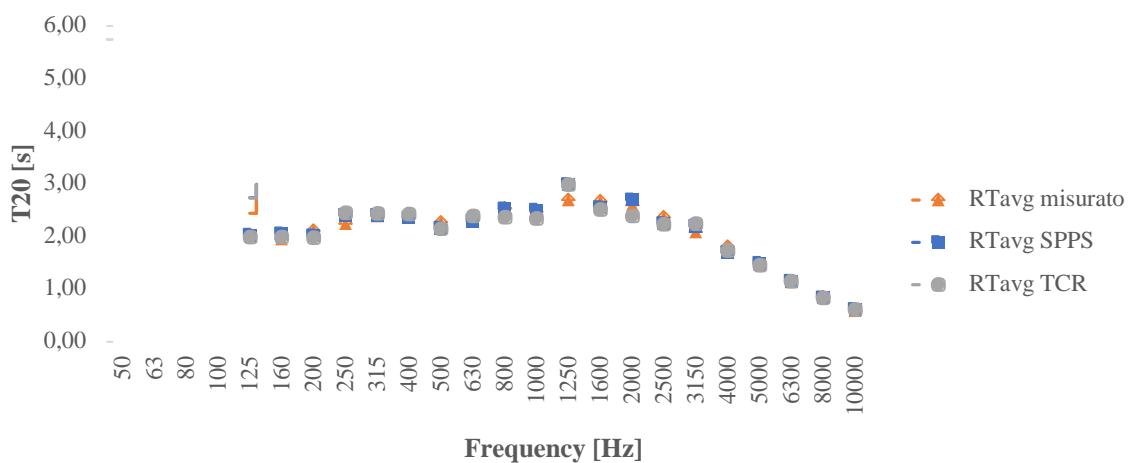
5.2.3.2 $\alpha_{M10\ avg}$ calibrated

The values of the absorption coefficients of the materials obtained from the calibration for the SPPS and TCR codes and the corresponding results in terms of reverberation time and relative percentage difference with the measured values are reported.

All values obtained are given in Annex C.6.

Frequency [Hz]	α SPPS	$\Delta\alpha [\%]$ SPPS	α TCR	$\Delta\alpha [\%]$ TCR
50	-	-	-	-
63	-	-	-	-
80	-	-	-	-
100	-	-	-	-
125	0,12	24,62%	0,10	-1,14%
160	0,12	24,02%	0,10	1,62%
200	0,12	27,67%	0,10	4,41%
250	0,10	20,95%	0,08	-2,63%
315	0,10	20,17%	0,08	2,20%
400	0,10	25,00%	0,08	2,25%
500	0,11	27,83%	0,09	6,76%
630	0,10	24,28%	0,08	2,46%
800	0,09	22,25%	0,08	6,31%
1000	0,09	23,68%	0,08	7,75%
1250	0,07	12,43%	0,06	-3,97%
1600	0,08	21,15%	0,07	8,88%
2000	0,07	18,47%	0,07	5,79%
2500	0,08	20,77%	0,07	8,01%
3150	0,07	6,86%	0,06	-4,84%
4000	0,08	18,44%	0,07	9,46%
5000	0,07	1,40%	0,07	-2,11%
6300	0,07	-0,04%	0,07	3,09%
8000	0,08	5,98%	0,08	6,59%
10000	0,09	-4,80%	0,09	-1,58%

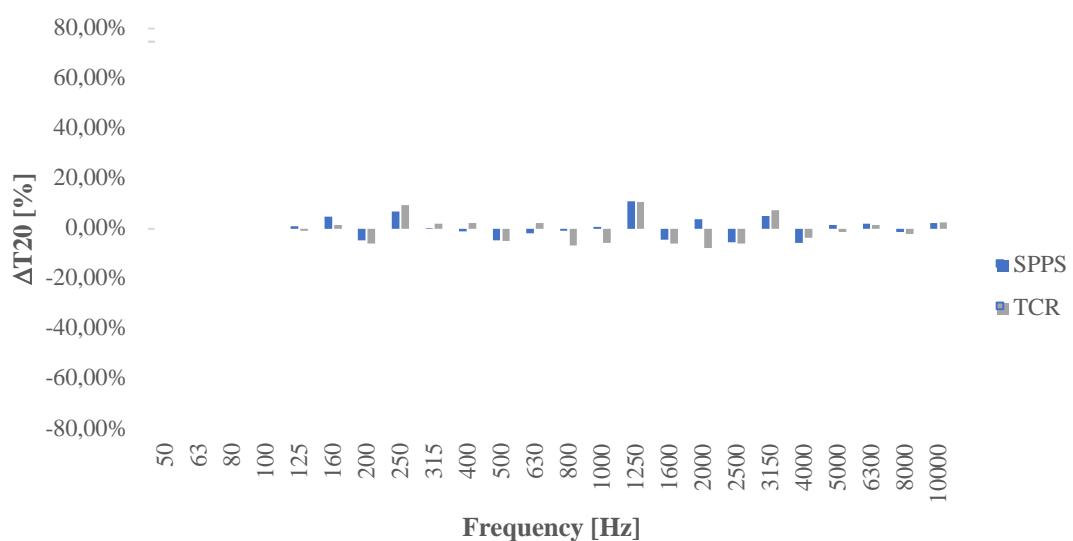
Table 5:29 Values of sound absorption coefficient calibrated and percentage difference between average sound absorption coefficient simulated and measured with SPPS and TCR codes



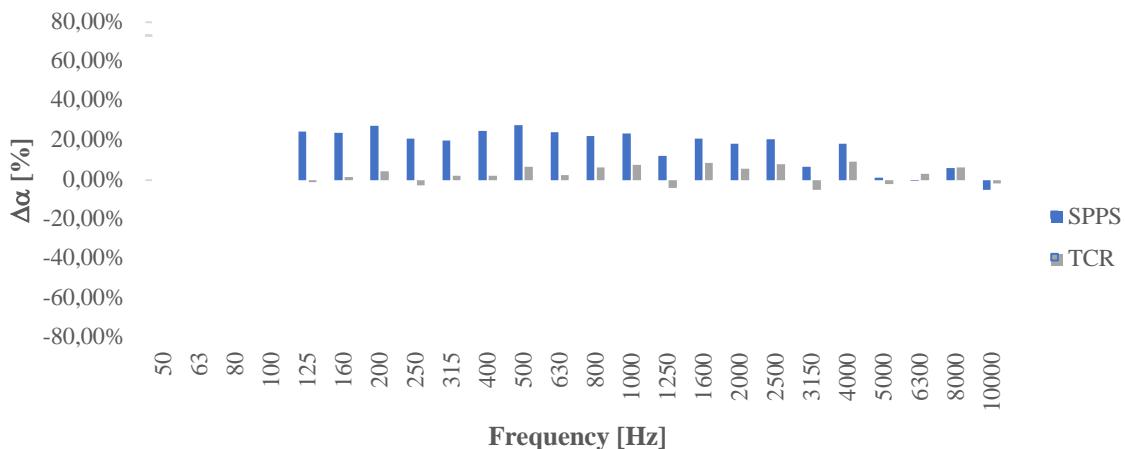
Graph 5:33 T20 average values measured and simulated with material average absorption coefficient calibrated with SPPS and TCR codes

Frequency [Hz]	$\Delta T20$ [s] SPPS method	$\Delta T20$ % SPPS method	$\Delta T20$ [s] TCR method	$\Delta T20$ % TCR method
50	-	-	-	-
63	-	-	-	-
80	-	-	-	-
100	-	-	-	-
125	-0,01	1,16%	0,02	-0,64%
160	-0,09	4,88%	-0,03	1,64%
200	0,09	-4,47%	0,13	-5,92%
250	-0,15	6,95%	-0,21	9,46%
315	-0,01	0,32%	-0,05	2,11%
400	0,02	-0,88%	-0,05	2,25%
500	0,10	-4,48%	0,11	-4,94%
630	0,04	-1,76%	-0,06	2,35%
800	0,02	-0,81%	0,17	-6,64%
1000	-0,02	0,74%	0,13	-5,54%
1250	-0,30	10,93%	-0,29	10,69%
1600	0,11	-4,21%	0,16	-5,81%
2000	-0,10	3,78%	0,20	-7,73%
2500	0,12	-5,30%	0,14	-5,84%
3150	-0,11	5,15%	-0,15	7,40%
4000	0,10	-5,67%	0,07	-3,69%
5000	-0,02	1,58%	0,02	-1,17%
6300	-0,02	2,04%	-0,01	1,45%
8000	0,01	-1,15%	0,02	-2,00%
10000	-0,01	2,35%	-0,02	2,57%

Table 5:30 Values of percentage difference between T20 simulated and measured with SPPS and TCR codes with average sound absorption coefficient calibrated

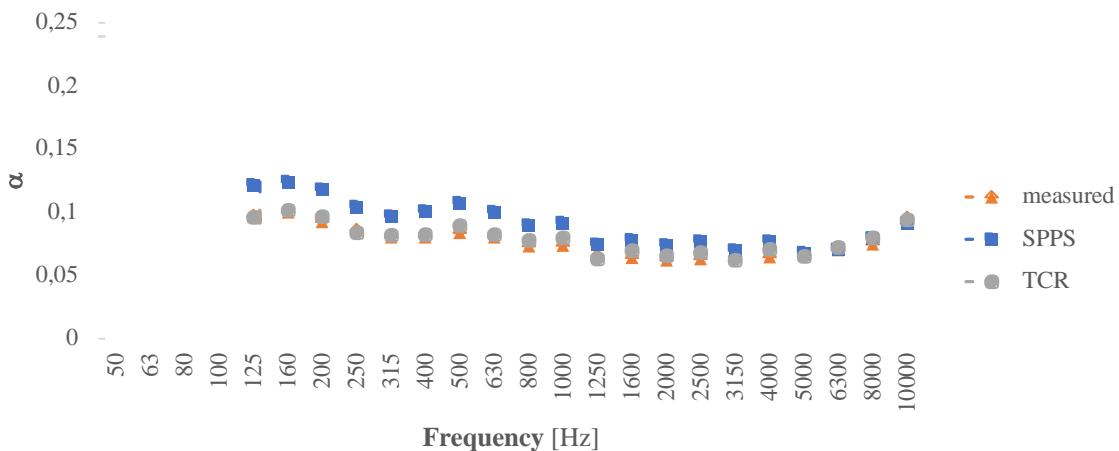


Graph 5:34 Representation of values present in table 5:30



Graph 5:35 Representation of values present in table 5:29

We therefore summarize in a single graph the trend of the absorption coefficient of the material measured and calibrated according to the two calculation codes proposed by I-Simpa.



Graph 5:36 Representation of sound absorption coefficient not calibrated and calibrated with SPPS and TCR codes from the values present in table 5:27 and 5:29

From graph 5:36, the measured absorption coefficient values are lower than those found with the SPPS code calibration. Instead it is very similar to the values obtained by calibration with the TCR code. However, this does not imply an equality in terms of reverberation time as there is always a difference between the measured and simulated reverberation times.

Conclusions

The thesis work focused on two main themes:

- the assessment of the intelligibility of speech in three environments;
- the evaluation of the best approach to EVAC design.

In order to address these issues, it was necessary to study the fundamental standards of alarm systems and techniques for measuring the acoustic characterization parameters of environments.

For the evaluation of speech intelligibility as well as for the evaluation of an EVAC system design, three classrooms of the University of Padua, classrooms M5, M6 and M10, were taken as reference.

From the studies carried out on the intelligibility of classrooms through the measurement of the parameter STIPA and through its analysis considering the various possibilities of background noise that may be present in normal classroom conditions we can say that:

- M5: the minimum intelligibility requirements of ISO 7240-19 are met both in the anthropic noise condition and with the addition of projector noise;
- M6: the minimum requirements of ISO 7240-19 are only met in the presence of anthropic noise. In the noise condition including the projector on, the average value requirement of $STIPA > 0.50$ is not met. In the other case considered, that is, when the noise coming from the activation of the hand dryer in the bathroom adjacent to the classroom is added, the minimum requirements are not met.
- M10: does not comply with the minimum intelligibility values either with the TalkBox level at 60 dB or 70 dB. It should be noted that the values obtained in this case are those obtained by measuring in conditions of anthropic noise only (noise in which the presence of the heating and lighting systems on is also considered). In case of normal lessons there is also the presence of the projector on, with the addition of other background noise which further affects the intelligibility value of speech.

The main problem that causes the lack of meeting the requirements of the intelligibility of the pearl in the environments studied is the reverberation time which is very high compared to the

maximum value required by ISO 7240-19, this means that the materials are not sufficiently absorbed, for this reason in order to improve the intelligibility of speech it is reasonable to add absorbent material.

As seen in §3.2.2.3 and §3.2.3.3 (paragraphs dealing with M6 and M10 or the most problematic classrooms), going to evaluate the value of the equivalent absorption area between the measured reverberation time values and those that would be obtained considering a maximum reverberation time value of 1.3 s (maximum acceptable value) we obtain:

- M6: an average percentage difference in the bands (400 Hz - 2500 Hz) compared to the measured values of -9.96% and therefore in terms of m^2 we should add an average equivalent absorption area of $1.36 m^2$.

In terms of the absorption coefficient of the material, considering all the surfaces that make up the environment, we should have an average coefficient of 0.063, in reality we have a coefficient of 0.062. A small amount of absorbing material should therefore be added.

- M10: an average percentage difference in the bands (400 Hz - 2500 Hz) compared to the measured values of -50.05% and therefore in terms of m^2 we should add an equivalent sound absorption area of $82.87 m^2$.

In terms of the absorption coefficient of the material, considering all the surfaces that make up the environment would mean that we should have a coefficient of 0.144, in reality we have an average value of 0.072, half of what it should ideally be.

These values have been obtained considering the maximum permissible reverberation time limit. In order to have better values we should therefore add more absorbent material.

It is desirable to distribute the absorbent material evenly over the surfaces of the environment or in the environment. Low frequency performance materials are effective in the proximity of the sound source, in the corners or edges of the room.

For rectangular rooms it may be useful to create a reflective central ceiling. In rooms with a volume of up to about $250 m^3$ a fully absorbent ceiling can be used.

It should be noted that the measurements were taken in January, at the beginning of the session and with little lecture activity, and therefore with few students present in the Department. In different periods of the year, even with changing seasons, the intelligibility values may change

as there may be different activities of presence of people even outside the department (such as activities in green areas). It can be said that the period in which the measurements were taken is the one that provides the best values. In the normal course of the teaching activity, when the efficiency of EVAC systems is even more important, the intelligibility of the classrooms is worse than that measured, with the consequent failure to meet the minimum requirements provided by ISO 7240-19.

In the phase concerning the study of the values obtained from the acoustic simulations in the rooms under study in order to identify the error that can be made when designing an EVAC system with the help of acoustic software, it was obtained that, considering the rooms made of a single material with an absorption coefficient obtained from the average measured reverberation time and considering the rooms in the real situation or with differentiation of the materials with values of absorption coefficients obtained from literature, we can say that it is impossible to obtain immediate results equivalent to reality. In order to obtain values, close to those measured it is fundamental to carry out a calibration process of the model. Only in this way it is possible to decrease the difference between the values of the measured and simulated parameters. Especially in the case of different materials as the assignment of the appropriate description and corresponding absorption coefficient of the literature material is not certain. Such as the fact that it is not always possible to find the absorption coefficient of the material of interest because it is not an obligation of the supplier.

It was also observed that the method that provides less difference between measured and simulated is through the differentiation of materials, this is due to the fact that it is possible to better correct the coefficients that contribute differently to the absorption of sound depending on their extension within the environment.

If I-Simpa is able to provide values close to those measured at the first simulation in all frequencies in the case of assigning a single absorption coefficient of the material obtained from the average measured reverberation time, this is not true in the case of material differentiation. In the latter case it is possible to observe how the simulated values differ substantially in the frequencies below Schroeder's frequency. This is an indication that the software does not model modal resonances.

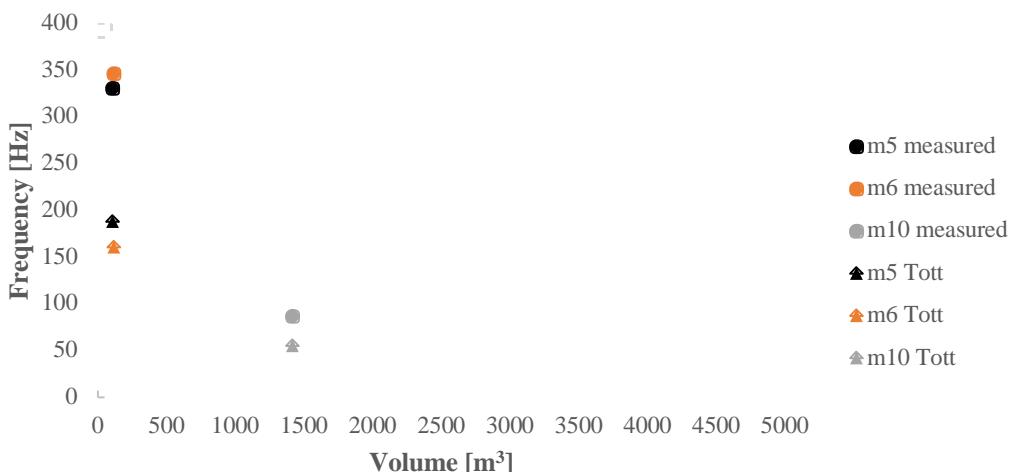
It can therefore be said that, for the design of EVAC systems through acoustic simulation software, the most correct method is through the differentiation of the materials in the environment but only after calibration.

In the case of a building under construction, it will therefore be appropriate to carry out acoustic measurement campaigns even on an open site, so that the model can be corrected in the best way. With an existing building instead, in addition to the measurement campaigns to calibrate the model, it will be appropriate to verify the sound pressure level of the loudspeakers and if necessary calibrate them so as to have audible values.

With reference to Schroeder's Frequency analysis and therefore to the limits of validity of the sound equations of classical theory associated with I-Simpa room modeling, we can see that, considering the frequency obtained from the optimal reverberation times obtained according to the method described in UNI 11532-2, in larger rooms we have more proximity of the optimal values with those measured (table A and graph A). Otherwise we have great differences between optimal and measured values in smaller rooms. From this it can be more inferred that, because I-Simpa works well in the field beyond Schroeder's frequency, we have more reliability in case of simulations in larger environments.

	Volume [m³]	f_s measured [Hz]	f_{sott} [Hz]
M5	107,2	331	188
M6	115,3	347	161
M10	1414,5	87	55

Table A Values of f_s measured and f_s ott calculated with 11532-2



Graph A values of f_s in relation with volume of environments

Annex A – M5

A.1 - B/N measurement in the 1st case (anthropic noise)

Receivers positions	1	2	3	4	5	6	7	8	9	10
Band [Hz]	Lzeq [dB]									
6,3	45,8	44,7	43,6	45,7	43,4	42,9	55,3	45,8	43,4	44,0
8	45,4	41,8	42,4	45,6	40,2	41,1	59,7	43,2	40,7	41,6
10	42,3	42,1	43,7	44,5	40,5	41,1	56,3	42,5	40,1	42,7
12,5	38,5	40,0	40,2	40,1	39,4	37,6	48,8	41,0	37,7	40,8
16	41,0	41,5	40,7	42,3	36,3	36,5	40,0	39,2	38,7	39,8
20	38,3	40,3	45,5	45,8	34,3	32,7	36,9	41,4	36,0	37,6
25	45,5	49,4	52,1	51,5	44,1	43,3	49,7	48,6	43,3	46,6
31,5	42,5	42,4	43,5	43,6	44,5	46,9	54,2	51,5	40,7	45,0
40	29,2	37,5	44,8	39,5	34,4	37,2	40,2	41,3	33,9	33,3
50	40,5	50,8	40,5	50,4	42,4	42,8	39,1	43,2	43,4	42,8
63	41,8	46,4	39,0	44,9	38,0	36,7	37,4	38,7	40,0	40,1
80	37,7	38,6	38,5	39,7	36,7	38,4	40,3	42,4	36,9	32,0
100	36,4	40,3	37,4	38,5	34,9	40,4	40,3	43,1	42,1	38,4
125	36,7	35,8	36,1	37,3	33,6	36,9	39,0	40,5	44,3	39,2
160	32,8	32,4	35,6	30,5	30,1	34,6	32,2	40,2	31,5	35,8
200	33,8	30,6	33,9	28,8	31,3	34,6	31,7	39,1	32,8	34,1
250	29,8	31,9	32,2	27,5	27,4	30,4	27,9	37,5	28,5	28,6
315	33,8	34,6	35,8	29,0	33,1	33,1	32,9	36,5	31,1	36,1
400	28,9	25,6	29,0	26,9	25,0	32,0	26,3	35,6	25,7	25,6
500	28,4	27,3	30,2	27,0	26,1	30,9	26,7	30,7	27,6	26,3
630	28,2	26,5	30,7	29,2	27,3	33,2	28,9	30,2	29,4	29,0
800	24,0	22,4	24,9	22,1	21,7	27,8	23,3	26,1	25,3	23,8
1000	23,3	21,7	23,6	22,0	20,9	25,7	23,5	23,5	24,2	24,0
1250	22,5	22,2	23,9	19,8	21,0	26,4	22,6	22,3	22,9	22,6
1600	22,1	20,7	23,7	20,2	20,1	25,4	22,6	21,2	21,9	22,3
2000	19,5	18,4	21,0	18,3	17,6	23,3	20,3	19,5	20,3	20,1
2500	18,2	16,6	20,2	16,5	16,1	23,7	19,4	18,5	20,4	19,6
3150	15,8	15,2	19,3	15,7	15,2	21,7	17,1	16,3	18,5	18,2
4000	15,4	15,2	16,2	15,3	15,1	20,9	16,3	16,0	16,5	16,4
5000	15,6	15,5	15,8	15,6	15,5	16,8	16,0	16,2	15,8	15,7
6300	16,1	16,0	16,2	16,1	16,2	17,0	16,2	16,2	16,4	16,4
8000	16,8	16,8	16,8	16,8	16,8	17,1	16,8	16,9	16,8	16,8
10000	17,5	17,6	17,5	17,5	17,5	17,5	17,5	17,5	17,5	17,5
12500	18,4	18,4	18,4	18,4	18,4	18,4	18,4	18,4	18,4	18,4
16000	19,4	19,4	19,4	19,4	19,4	19,4	19,4	19,4	19,5	19,4
20000	20,4	20,4	20,5	20,4	20,5	20,5	20,4	20,5	20,5	20,5

A.2 - B/N measurement in the 2nd case (anthropic noise +projector)

Receivers positions	1	2	3	4	5	6	7	8	9	10
Band [Hz]	Lzeq [dB]									
6,3	43,5	42,1	44,8	44,8	45,0	45,2	42,1	49,4	51,1	44,4
8	41,5	39,7	42,4	42,4	42,9	43,6	39,7	47,9	52,6	41,8
10	39,8	40,1	41,9	42,6	42,2	41,7	40,1	45,5	49,6	41,5
12,5	38,5	38,2	40,2	43,0	41,6	40,3	38,2	44,9	44,4	40,6
16	39,9	38,8	41,4	42,7	37,2	38,1	38,8	41,1	40,6	39,9
20	39,3	37,7	40,3	44,8	38,5	34,4	37,7	46,2	39,4	42,7
25	46,3	48,8	52,6	54,0	45,5	46,1	48,8	52,9	45,7	47,1
31,5	42,1	40,5	44,0	46,6	46,4	49,7	40,5	52,8	42,9	45,2
40	28,7	33,8	41,8	44,0	36,9	42,2	33,8	44,5	35,3	38,2
50	40,1	37,0	40,9	43,3	46,4	48,1	37,0	46,2	43,7	46,1
63	39,5	37,4	37,2	41,1	40,8	41,4	37,4	46,1	41,1	42,8
80	37,4	38,8	44,0	40,4	38,5	42,8	38,8	44,0	40,1	33,4
100	37,8	37,7	43,7	38,6	37,0	47,4	37,7	46,2	45,4	37,8
125	37,7	36,1	44,0	38,6	36,1	43,0	36,1	42,9	44,2	38,8
160	30,9	34,5	42,1	33,3	36,0	39,9	34,5	41,5	40,0	33,7
200	34,0	33,3	40,3	31,1	33,1	39,5	33,3	36,9	38,6	35,1
250	30,8	31,3	38,3	30,1	31,3	38,7	31,3	37,7	37,4	31,1
315	33,4	33,4	40,2	33,2	34,4	38,0	33,4	38,8	37,7	35,6
400	31,7	29,6	34,1	29,1	30,2	37,6	29,6	36,4	35,0	30,4
500	40,8	43,4	44,1	40,0	40,4	45,6	43,4	39,1	42,2	37,6
630	36,2	35,6	35,7	34,4	35,3	38,8	35,6	36,9	36,1	34,3
800	36,9	38,9	38,2	37,3	39,2	39,6	38,9	36,7	37,0	36,4
1000	35,9	36,6	36,0	36,1	35,7	37,2	36,6	36,2	38,2	34,9
1250	35,3	33,9	33,9	33,4	34,3	35,5	33,9	35,9	34,9	33,2
1600	37,0	36,6	35,9	35,6	36,8	38,2	36,6	37,6	37,4	40,6
2000	32,3	32,2	33,2	32,1	34,1	34,5	32,2	33,9	33,2	32,8
2500	30,4	29,9	29,6	29,8	30,6	32,1	29,9	32,3	32,6	30,3
3150	26,9	26,0	26,0	25,5	26,4	28,4	26,0	26,3	27,9	26,3
4000	26,6	26,6	27,0	26,0	26,9	27,3	26,6	26,2	26,8	26,2
5000	25,6	25,8	26,1	25,1	26,5	26,2	25,8	25,6	25,6	25,7
6300	23,2	22,8	23,4	22,9	24,7	24,1	22,8	23,2	23,7	23,3
8000	21,0	20,6	20,7	20,5	21,8	21,6	20,6	20,7	21,0	21,1
10000	18,7	18,5	18,5	18,5	19,2	18,9	18,5	18,7	18,8	18,8
12500	18,6	18,6	18,6	18,6	18,8	18,7	18,6	18,7	18,7	18,7
16000	19,5	19,5	19,5	19,5	19,6	19,5	19,5	19,5	19,5	19,5
20000	20,5	20,5	20,5	20,5	20,8	20,7	20,5	20,6	20,6	20,6

A.3 - Reverberation Time measurement

source-receiver s position s	A-2		B-2		C-2		A-7		B-7		C-7	
n. measur ement	1	2	1	2	1	2	1	2	1	2	1	2
Band [Hz]	RT60(T20) [s]											
50	1,51	3,04	1,97	1,75	0,39	1,81	2,56	--	--	--	3,24	1,51
63	1,13	2,09	1,88	1,64	--	--	1,90	--	2,01	2,69	1,07	1,13
80	2,51	2,63	1,96	2,12	1,65	1,91	2,55	2,53	2,69	2,02	2,53	2,51
100	2,92	2,96	2,55	2,60	2,85	3,10	2,47	3,09	3,73	3,10	2,94	2,92
125	2,11	1,33	1,63	1,48	1,52	1,62	1,07	1,05	1,89	2,01	2,19	2,11
160	1,56	1,14	1,70	1,66	1,32	1,33	1,74	1,82	1,44	1,46	1,61	1,56
200	1,39	1,17	1,28	1,25	1,26	1,27	1,46	1,44	1,34	1,34	1,37	1,39
250	1,18	1,26	1,19	1,22	1,25	1,31	1,16	1,18	1,32	1,36	1,26	1,18
315	1,09	1,38	1,17	1,17	1,24	1,17	1,20	1,18	1,10	1,11	1,16	1,09
400	1,24	1,06	1,13	1,12	1,13	1,15	1,24	1,22	1,20	1,16	1,24	1,24
500	1,06	1,16	1,20	1,25	1,16	1,20	1,13	1,17	1,02	1,09	1,17	1,06
630	1,07	1,12	1,12	1,22	1,19	1,17	1,21	1,22	1,18	1,24	1,16	1,07
800	1,18	1,30	1,33	1,27	1,33	1,38	1,21	1,20	1,14	1,20	1,20	1,18
1000	1,20	1,21	1,18	1,25	1,26	1,24	1,24	1,29	1,24	1,22	1,23	1,20
1250	1,19	1,18	1,19	1,32	1,36	1,36	1,18	1,16	1,33	1,27	1,28	1,19
1600	1,22	1,22	1,28	1,19	1,25	1,26	1,15	1,17	1,16	1,19	1,22	1,22
2000	1,23	1,22	1,17	1,20	1,20	1,15	1,25	1,17	1,19	1,14	1,14	1,23
2500	1,19	1,15	1,12	1,12	1,19	1,12	1,16	1,14	1,11	1,17	1,12	1,19
3150	1,13	1,06	1,14	1,11	1,12	1,13	1,15	1,12	1,10	1,06	1,06	1,13
4000	1,05	1,04	1,07	1,06	1,06	1,07	1,05	1,05	1,05	1,05	1,05	1,05
5000	0,94	0,93	0,94	0,97	0,93	0,92	0,92	0,94	0,93	0,92	0,97	0,94
6300	0,85	0,81	0,80	0,81	0,78	0,81	0,84	0,87	0,78	0,82	0,79	0,85
8000	0,70	0,66	0,68	0,66	0,69	0,71	0,71	0,69	0,68	0,68	0,71	0,70
10000	0,57	0,52	0,54	0,54	0,56	0,56	0,54	0,55	0,57	0,56	0,54	0,57

A.4 - Reverberation time with SPPS and TCR codes with α_{M5} literature

source-receiver position	RT SPPS code					RT TCR code	
	A-2	B-2	C-2	A-7	B-7	C-7	
Band [Hz]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]
50	1,00	0,99	0,98	1,02	0,99	0,99	0,86
63	0,98	0,95	0,98	1,00	0,97	0,98	0,86
80	1,01	0,99	1,02	1,00	0,97	1,00	0,86
100	1,02	1,02	1,04	0,98	0,99	0,97	0,86
125	1,01	0,98	0,99	0,99	0,96	0,98	0,86
160	1,00	0,96	1,02	0,97	0,96	1,02	0,86
200	1,00	1,01	0,99	0,99	1,00	1,01	0,88
250	1,00	1,03	0,99	0,98	1,00	1,02	0,88
315	0,99	1,00	0,99	0,99	1,00	1,01	0,88
400	1,40	1,44	1,47	1,47	1,44	1,44	1,18
500	1,46	1,44	1,42	1,48	1,46	1,43	1,18
630	1,39	1,41	1,39	1,44	1,42	1,40	1,17
800	1,53	1,60	1,59	1,55	1,62	1,56	1,25
1000	1,62	1,59	1,60	1,55	1,56	1,59	1,25
1250	1,60	1,55	1,63	1,55	1,54	1,64	1,24
1600	1,65	1,74	1,63	1,70	1,66	1,65	1,30
2000	1,56	1,58	1,64	1,59	1,63	1,62	1,27
2500	1,57	1,47	1,54	1,57	1,55	1,56	1,23
3150	1,59	1,64	1,54	1,55	1,56	1,58	1,27
4000	1,41	1,39	1,35	1,40	1,36	1,43	1,17
5000	1,22	1,17	1,21	1,19	1,20	1,16	1,04
6300	0,94	0,95	0,93	0,96	0,95	0,93	0,84
8000	0,74	0,75	0,76	0,76	0,74	0,73	0,69
10000	0,57	0,58	0,58	0,57	0,58	0,59	0,55

A.5 - Reverberation Time with SPPS and TCR code with α_{M5} lit calibrated

source-receiver positions	RT SPPS code					RT TCR code	
	A-2	B-2	C-2	A-7	B-7	C-7	
Band [Hz]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]
50	1,98	1,94	1,94	1,96	2,05	1,91	1,96
63	1,90	1,90	1,87	1,85	1,87	1,86	1,82
80	2,44	2,41	2,31	2,42	2,33	2,34	2,26
100	2,94	2,98	2,93	2,91	2,91	2,91	2,99
125	1,76	1,67	1,68	1,67	1,69	1,66	1,62
160	1,69	1,70	1,60	1,62	1,60	1,56	1,53
200	1,48	1,54	1,51	1,47	1,52	1,48	1,37
250	1,35	1,35	1,31	1,33	1,34	1,34	1,25
315	1,35	1,27	1,32	1,31	1,29	1,31	1,20
400	1,22	1,19	1,20	1,21	1,21	1,18	1,18
500	1,19	1,17	1,19	1,14	1,20	1,19	1,18
630	1,18	1,19	1,21	1,22	1,17	1,20	1,17
800	1,28	1,31	1,31	1,32	1,24	1,28	1,25
1000	1,29	1,27	1,27	1,28	1,29	1,25	1,25
1250	1,29	1,21	1,23	1,26	1,28	1,27	1,24
1600	1,21	1,28	1,31	1,25	1,28	1,26	1,25
2000	1,20	1,25	1,24	1,23	1,26	1,27	1,22
2500	1,19	1,21	1,18	1,17	1,22	1,21	1,18
3150	1,12	1,09	1,11	1,15	1,12	1,10	1,11
4000	1,11	1,09	1,10	1,07	1,13	1,10	1,03
5000	0,96	0,94	0,95	0,94	0,95	0,95	0,94
6300	0,84	0,85	0,85	0,84	0,86	0,84	0,84
8000	0,69	0,69	0,68	0,68	0,67	0,68	0,69
10000	0,56	0,56	0,54	0,54	0,54	0,56	0,55

A.6 – Reverberation Time with SPPS and TCR codes with α_{M5} avg

source-receiver positions	RT SPPS code					RT TCR code	
	A-2	B-2	C-2	A-7	B-7	C-7	
Band [Hz]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]
50	2,64	2,60	2,58	2,49	2,56	2,64	2,15
63	2,05	2,04	2,06	2,13	2,07	2,04	1,72
80	2,57	2,58	2,54	2,54	2,54	2,58	2,15
100	3,31	3,29	3,30	3,26	3,26	3,36	2,85
125	2,11	2,15	2,11	2,10	2,11	2,07	1,71
160	1,73	1,67	1,75	1,69	1,77	1,71	1,43
200	1,73	1,75	1,76	1,74	1,74	1,78	1,42
250	1,48	1,46	1,47	1,49	1,49	1,50	1,22
315	1,53	1,47	1,50	1,45	1,50	1,54	1,22
400	1,48	1,45	1,47	1,51	1,52	1,54	1,21
500	1,52	1,51	1,49	1,51	1,49	1,49	1,21
630	1,46	1,45	1,44	1,48	1,53	1,50	1,20
800	1,45	1,53	1,47	1,46	1,42	1,45	1,20
1000	1,47	1,46	1,44	1,47	1,43	1,50	1,19
1250	1,38	1,39	1,45	1,44	1,43	1,41	1,18
1600	1,41	1,40	1,41	1,41	1,36	1,43	1,17
2000	1,40	1,33	1,40	1,36	1,37	1,33	1,14
2500	1,34	1,28	1,32	1,28	1,29	1,30	1,11
3150	1,23	1,23	1,24	1,24	1,22	1,20	1,06
4000	1,26	1,25	1,26	1,23	1,22	1,29	1,11
5000	1,00	0,98	0,99	1,01	0,97	0,99	0,90
6300	0,90	0,91	0,92	0,90	0,91	0,90	0,86
8000	0,72	0,74	0,72	0,75	0,72	0,74	0,71
10000	0,58	0,57	0,58	0,58	0,56	0,59	0,56

A.7 – Reverberation Time with SPPS and TCR code with $\alpha_{M5\ avg}$ calibrated

source-receiver positions	RT SPPS code						RT TCR code
	A-2	B-2	C-2	A-7	B-7	C-7	
Band [Hz]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]
50	1,72	1,80	1,81	1,74	1,80	1,80	1,72
63	1,78	1,77	1,76	1,76	1,70	1,79	1,72
80	2,61	2,66	2,62	2,61	2,56	2,57	2,86
100	3,41	3,21	3,33	3,30	3,34	3,35	2,85
125	1,75	1,79	1,73	1,78	1,73	1,71	1,71
160	1,72	1,75	1,77	1,82	1,73	1,77	1,71
200	1,28	1,31	1,25	1,37	1,34	1,34	1,22
250	1,33	1,31	1,38	1,32	1,35	1,33	1,22
315	1,18	1,21	1,19	1,17	1,21	1,14	1,22
400	1,21	1,18	1,14	1,20	1,14	1,16	1,21
500	1,10	1,06	1,06	1,05	1,02	1,04	1,06
630	1,16	1,13	1,25	1,16	1,14	1,16	1,20
800	1,29	1,29	1,29	1,26	1,30	1,33	1,39
1000	1,25	1,29	1,31	1,28	1,26	1,31	1,38
1250	1,27	1,25	1,26	1,30	1,26	1,32	1,37
1600	1,22	1,22	1,25	1,31	1,21	1,25	1,35
2000	1,21	1,23	1,23	1,19	1,23	1,26	1,32
2500	1,16	1,14	1,18	1,18	1,17	1,19	1,27
3150	1,22	1,21	1,31	1,22	1,20	1,22	1,21
4000	1,00	1,00	1,06	1,01	0,97	1,04	0,99
5000	0,99	0,99	0,99	1,00	0,99	1,00	1,00
6300	0,77	0,79	0,77	0,79	0,76	0,78	0,78
8000	0,68	0,69	0,71	0,68	0,66	0,68	0,65
10000	0,54	0,55	0,54	0,54	0,55	0,53	0,53

Annex B – M6

B.1 - B/N measurements in the 1st case (anthropic noise)

Receivers positions	1	2	3	4	5
Band [Hz]	Lzeq [dB]	Lzeq [dB]	Lzeq [dB]	Lzeq [dB]	Lzeq [dB]
6,3	49,6	50,8	49,5	48,4	48,2
8	54,2	55,6	53,6	53,2	54,5
10	49,5	52,2	50,2	50,5	50,0
12,5	42,1	43,7	39,9	41,4	38,7
16	46,1	46,3	41,1	41,1	37,9
20	43,7	46,1	43,6	44,8	37,0
25	53,7	56,0	51,6	52,8	43,5
31,5	40,6	52,8	39,7	49,6	43,8
40	31,6	42,0	32,1	40,5	34,0
50	40,9	40,2	40,7	39,9	47,5
63	42,7	40,4	40,3	38,3	38,7
80	39,2	37,8	35,3	39,7	33,4
100	39,3	37,0	37,3	33,3	35,3
125	41,3	36,4	38,0	35,1	33,6
160	45,2	33,9	34,8	37,3	33,2
200	39,9	33,7	36,0	37,4	36,3
250	32,8	29,7	32,8	31,6	28,3
315	34,5	33,5	31,1	33,0	32,5
400	27,8	25,9	28,7	28,9	25,4
500	29,2	27,5	29,3	27,0	25,4
630	27,8	25,4	27,9	27,6	22,7
800	24,7	23,0	27,9	25,7	21,0
1000	21,6	24,9	26,2	25,4	19,6
1250	20,5	29,0	26,5	24,0	19,6
1600	19,5	21,3	24,8	23,4	18,8
2000	19,1	19,6	22,6	22,3	18,4
2500	17,7	18,1	18,8	18,9	17,7
3150	17,6	17,6	17,3	16,6	15,7
4000	17,1	17,5	17,0	16,1	15,3
5000	16,1	16,7	16,8	15,9	15,6
6300	16,6	16,7	16,5	16,4	16,1
8000	17,0	17,2	17,0	16,9	16,8
10000	17,6	17,7	17,6	17,6	17,6
12500	18,5	18,5	18,4	18,3	18,4
16000	19,6	19,6	19,5	19,5	19,6
20000	20,6	20,6	20,5	20,6	20,6

B.2 - B/N measurement in the 2nd case (anthropic noise+projector).

Receivers positions	1	2	3	4	5
Band [Hz]	Lzeq [dB]				
6,3	51,2	51,0	50,7	49,1	48,1
8	53,0	55,1	54,7	55,2	54,3
10	48,5	52,7	51,3	48,8	50,4
12,5	44,5	46,3	44,0	39,7	40,0
16	43,8	50,4	47,9	40,9	39,7
20	42,3	47,6	45,7	44,2	38,4
25	52,1	56,5	51,1	53,7	41,9
31,5	38,9	57,1	42,0	52,3	42,6
40	29,1	48,2	34,1	39,5	32,7
50	37,4	40,7	42,2	42,6	43,5
63	40,2	41,6	45,3	38,3	37,7
80	33,4	41,9	39,3	37,6	34,8
100	35,8	40,5	42,2	36,1	40,4
125	35,4	42,5	45,0	36,3	38,5
160	35,1	43,5	45,0	34,1	37,6
200	34,9	41,0	43,7	36,1	37,3
250	28,6	36,9	37,5	32,0	35,2
315	31,6	37,8	38,5	33,5	36,8
400	29,7	36,9	36,1	32,4	34,7
500	37,2	37,0	35,9	36,4	36,9
630	35,1	36,4	35,9	34,8	36,1
800	35,6	35,6	34,1	35,7	35,1
1000	33,5	35,8	34,9	34,8	35,2
1250	34,7	34,5	34,6	34,6	34,5
1600	35,8	35,0	35,2	35,3	35,5
2000	31,5	31,3	30,6	31,2	31,1
2500	29,2	29,6	29,1	29,2	29,2
3150	26,2	25,3	25,0	25,0	25,7
4000	26,6	26,1	25,6	25,2	25,4
5000	25,4	25,0	25,1	25,2	25,3
6300	22,5	21,9	22,2	22,1	22,4
8000	20,6	19,9	20,2	20,2	20,8
10000	18,8	18,5	18,6	18,7	18,9
12500	18,7	18,6	18,6	18,6	18,7
16000	19,6	19,6	19,6	19,6	19,6
20000	20,8	20,7	20,6	20,6	20,7

B.3 - B/N measurement in the 3rd case (anthropic noise + projector + hand dryer)

Receivers positions	1	2	3	4	5
Band [Hz]	Lzeq [dB]				
6,3	49,3	50,5	50,1	47,4	47,9
8	52,4	54,4	54,9	51,6	52,7
10	49,1	50,4	50,4	48,3	49,2
12,5	39,7	43,4	41,5	40,5	39,9
16	46,4	44,6	42,0	43,2	42,4
20	43,7	44,7	44,0	45,2	38,8
25	54,0	54,5	53,5	53,4	44,9
31,5	42,5	49,5	38,3	50,6	47,1
40	31,5	40,6	33,7	42,2	38,2
50	38,3	39,3	43,1	40,9	46,7
63	39,6	38,4	39,3	39,6	41,2
80	40,9	40,7	38,6	45,4	40,3
100	61,5	58,4	47,9	59,2	59,9
125	57,6	54,6	54,9	51,1	57,4
160	39,7	38,5	39,4	42,8	40,4
200	49,7	44,3	53,5	48,0	54,3
250	39,3	43,1	40,1	42,6	41,1
315	38,8	42,2	37,8	40,7	40,4
400	38,9	41,1	39,8	42,1	41,9
500	46,6	41,1	43,2	46,0	45,9
630	42,9	47,5	42,3	47,6	45,6
800	42,5	45,3	41,4	46,7	43,7
1000	40,3	40,1	43,1	43,7	42,0
1250	39,7	39,1	39,7	40,5	39,7
1600	40,5	41,1	40,8	39,8	39,1
2000	34,0	34,3	33,7	34,2	34,5
2500	33,9	34,2	33,7	33,4	33,9
3150	31,0	30,7	30,5	30,5	30,8
4000	28,3	27,9	27,9	28,1	27,9
5000	26,3	26,0	26,2	26,3	26,1
6300	24,3	23,9	24,2	24,5	24,2
8000	21,1	20,9	21,0	21,1	21,2
10000	19,0	18,8	18,9	19,2	19,1
12500	18,7	18,6	18,6	18,8	18,8
16000	19,7	19,7	19,6	19,7	19,7
20000	20,7	20,6	20,6	20,6	20,7

B.4 - Reverberation Time Measurement

source-receive rs positio ns	A-2		B-2		C-2		A-3		B-3		C-3		
	n. measu rement	1	2	1	2	1	2	1	2	1	2	1	2
Band [Hz]	RT60 (T20) [s]	RT60 (T20) [s]	RT60 (T20) [s]	RT60 (T20) [s]	RT60 (T20) [s]	RT60 (T20) [s]	RT60 (T20) [s]	RT60 (T20) [s]	RT60 (T20) [s]	RT60 (T20) [s]	RT60 (T20) [s]	RT60 (T20) [s]	RT60 (T20) [s]
50	2,78	2,97	--	3,02	2,98	5,22	3,74	3,05	2,96	3,22	3,86	2,34	
63	2,24	2,45	1,66	3,99	2,23	3,93	2,95	2,82	2,82	3,00	2,60	2,35	
80	3,59	3,67	3,39	2,76	3,52	--	4,18	3,43	3,36	3,34	3,74	3,30	
100	2,53	2,51	2,83	2,84	2,70	3,08	2,67	2,68	2,80	3,00	2,38	2,44	
125	2,03	2,66	3,24	3,10	2,39	3,04	2,58	2,47	2,79	2,90	2,50	2,49	
160	2,29	2,38	2,12	2,12	2,39	2,30	2,52	2,73	2,06	2,48	1,80	1,79	
200	1,95	1,97	1,85	1,88	1,86	1,78	2,08	2,08	1,87	1,90	1,70	1,73	
250	1,71	1,77	1,62	1,59	1,55	1,51	1,60	1,62	1,70	1,68	1,43	1,48	
315	1,47	1,52	1,68	1,63	1,40	1,38	1,56	1,47	1,25	1,32	1,68	1,55	
400	1,55	1,62	1,62	1,61	1,52	1,48	1,60	1,65	1,51	1,52	1,54	1,56	
500	1,60	1,54	1,51	1,49	1,70	1,71	1,57	1,73	1,62	1,69	1,49	1,46	
630	1,79	1,53	1,56	1,39	1,54	1,40	1,44	1,49	1,43	1,42	1,57	1,53	
800	1,53	1,44	1,57	1,63	1,59	1,64	1,47	1,36	1,47	1,41	1,43	1,48	
1000	1,41	1,46	1,44	1,45	1,54	1,54	1,42	1,40	1,46	1,31	1,61	1,55	
1250	1,47	1,48	1,46	1,47	1,47	1,47	1,49	1,49	1,50	1,38	1,47	1,36	
1600	1,35	1,28	1,34	1,32	1,47	1,39	1,34	1,28	1,44	1,43	1,45	1,41	
2000	1,29	1,30	1,35	1,38	1,27	1,35	1,24	1,30	1,22	1,35	1,29	1,31	
2500	1,24	1,26	1,27	1,31	1,27	1,32	1,27	1,27	1,25	1,22	1,23	1,28	
3150	1,15	1,16	1,18	1,24	1,26	1,25	1,19	1,19	1,20	1,20	1,18	1,23	
4000	1,12	1,10	1,13	1,13	1,12	1,18	1,10	1,12	1,11	1,13	1,09	1,11	
5000	0,96	0,98	1,04	1,00	0,98	0,97	0,96	0,98	1,00	0,98	1,02	1,01	
6300	0,87	0,87	0,87	0,86	0,87	0,84	0,84	0,82	0,86	0,83	0,89	0,90	
8000	0,71	0,68	0,70	0,67	0,72	0,68	0,71	0,69	0,73	0,69	0,68	0,68	
10000	0,56	0,56	0,54	0,53	--	0,56	0,56	0,53	0,56	0,54	0,56	0,54	

B.5 - Reverberation time with SPPS and TCR methods with $\alpha_{M6\text{ lit}}$

source-receiver position	RT SPPS method						RT TCR method
	A-2	B-2	C-2	A-3	B-3	C-3	
Band [Hz]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]
50	1,06	1,04	1,05	1,03	1,04	1,03	0,94
63	1,03	1,06	1,06	1,04	1,03	1,05	0,94
80	1,06	1,04	1,05	1,02	1,04	1,03	0,94
100	1,07	1,01	1,02	1,01	1,01	1,03	0,94
125	1,00	1,02	1,05	1,07	1,05	1,06	0,94
160	1,03	1,02	1,05	1,04	1,04	1,05	0,94
200	1,06	1,02	1,03	1,09	1,06	1,06	0,97
250	1,04	1,06	1,03	1,05	1,04	1,07	0,97
315	1,05	1,04	1,07	1,03	1,03	1,04	0,96
400	1,68	1,64	1,62	1,68	1,67	1,64	1,35
500	1,58	1,73	1,65	1,68	1,71	1,64	1,34
630	1,62	1,61	1,66	1,65	1,61	1,63	1,34
800	1,89	1,94	1,85	1,90	1,92	1,90	1,43
1000	1,84	1,89	1,88	1,87	1,85	1,90	1,42
1250	1,84	1,84	1,79	1,80	1,82	1,84	1,41
1600	1,91	1,98	1,93	1,91	1,99	1,93	1,47
2000	1,88	1,88	1,83	1,87	1,86	1,86	1,43
2500	1,69	1,75	1,81	1,74	1,69	1,80	1,37
3150	1,74	1,86	1,70	1,81	1,79	1,72	1,41
4000	1,45	1,45	1,51	1,55	1,46	1,51	1,28
5000	1,25	1,28	1,28	1,28	1,26	1,25	1,12
6300	0,98	1,00	0,99	0,99	0,96	0,97	0,88
8000	0,76	0,74	0,74	0,73	0,75	0,76	0,71
10000	0,58	0,59	0,58	0,59	0,59	0,59	0,56

B.6 - Reverberation time with SPPS and TCR codes with α_{M6} lit calibrated

source-receiver positions	RT SPPS code					RT TCR code	
	A-2	B-2	C-2	A-3	B-3	C-3	
Band [Hz]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]
50	3,41	3,27	3,42	3,45	3,38	3,36	3,29
63	2,72	2,71	2,69	2,68	2,71	2,75	2,72
80	3,44	3,55	3,56	3,53	3,57	3,43	3,28
100	2,74	2,72	2,78	2,61	2,69	2,67	2,72
125	2,77	2,65	2,69	2,72	2,68	2,71	2,71
160	2,26	2,17	2,27	2,26	2,28	2,20	2,17
200	1,91	1,93	1,91	1,98	1,89	1,92	1,79
250	1,65	1,63	1,63	1,65	1,59	1,69	1,58
315	1,54	1,44	1,46	1,46	1,50	1,48	1,49
400	1,67	1,64	1,71	1,69	1,68	1,61	1,54
500	1,62	1,70	1,63	1,65	1,61	1,67	1,53
630	1,50	1,46	1,45	1,53	1,48	1,45	1,52
800	1,50	1,51	1,58	1,49	1,49	1,54	1,43
1000	1,51	1,49	1,46	1,52	1,47	1,48	1,42
1250	1,44	1,46	1,44	1,46	1,47	1,47	1,41
1600	1,44	1,49	1,45	1,41	1,38	1,45	1,41
2000	1,40	1,41	1,35	1,47	1,32	1,39	1,26
2500	1,27	1,34	1,35	1,34	1,33	1,29	1,24
3150	1,29	1,27	1,24	1,30	1,27	1,32	1,20
4000	1,22	1,20	1,25	1,21	1,24	1,18	1,10
5000	1,04	1,05	1,05	1,08	1,04	1,05	0,99
6300	0,90	0,90	0,90	0,87	0,87	0,89	0,88
8000	0,71	0,72	0,71	0,70	0,70	0,69	0,71
10000	0,55	0,55	0,55	0,56	0,55	0,55	0,55

B.7 - Reverberation time with SPPS and TCR codes with α_{M6} avg

source-receiver positions	RT SPPS code					RT TCR code	
	A-2	B-2	C-2	A-3	B-3	C-3	
Band [Hz]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]
50	3,68	3,71	3,74	3,69	3,66	3,65	3,16
63	3,68	3,72	3,67	3,71	3,70	3,65	3,16
80	3,63	3,72	3,59	3,74	3,63	3,66	3,15
100	3,66	3,63	3,68	3,65	3,64	3,69	3,15
125	3,60	3,64	3,66	3,59	3,60	3,62	3,14
160	2,84	2,91	2,86	2,90	2,91	2,91	2,35
200	2,31	2,29	2,24	2,34	2,34	2,28	1,88
250	1,91	1,98	1,88	1,92	1,89	1,94	1,56
315	1,87	1,88	1,93	1,93	1,94	2,01	1,56
400	1,89	1,92	1,88	1,88	1,85	1,95	1,55
500	1,91	1,88	1,97	1,88	1,91	1,95	1,55
630	1,84	1,91	1,92	1,90	1,89	1,92	1,54
800	1,88	1,87	1,83	1,87	1,83	1,86	1,53
1000	1,83	1,85	1,84	1,89	1,87	1,86	1,52
1250	1,84	1,83	1,81	1,89	1,76	1,77	1,50
1600	1,79	1,71	1,81	1,79	1,76	1,77	1,48
2000	1,50	1,51	1,46	1,45	1,46	1,50	1,25
2500	1,42	1,43	1,39	1,39	1,35	1,40	1,21
3150	1,30	1,34	1,31	1,31	1,30	1,30	1,14
4000	1,30	1,28	1,32	1,32	1,27	1,29	1,19
5000	1,00	1,05	1,03	1,03	1,03	1,02	0,95
6300	0,94	0,93	0,93	0,92	0,95	0,92	0,89
8000	0,70	0,69	0,69	0,70	0,69	0,70	0,67
10000	0,55	0,54	0,55	0,56	0,54	0,55	0,54

B.8 – Reverberation time with SPPS and TCR codes with α_{M6} avg calibrated

source-receiver positions	RT SPPS code					RT TCR code	
	A-2	B-2	C-2	A-3	B-3	C-3	
Band [Hz]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]
50	3,67	3,71	3,72	3,59	3,72	3,58	3,16
63	2,25	2,26	2,38	2,36	2,33	2,41	2,37
80	3,74	3,60	3,65	3,61	3,66	3,70	4,72
100	2,34	2,30	2,27	2,36	2,35	2,37	2,36
125	2,40	2,36	2,37	2,32	2,36	2,29	2,36
160	2,28	2,38	2,56	2,25	2,25	2,26	2,35
200	1,94	1,95	1,93	1,95	1,83	1,88	1,88
250	1,70	1,65	1,65	1,68	1,66	1,67	1,56
315	1,46	1,48	1,48	1,43	1,42	1,43	1,56
400	1,69	1,68	1,71	1,67	1,59	1,70	1,55
500	1,63	1,62	1,60	1,65	1,62	1,68	1,55
630	1,37	1,43	1,42	1,44	1,42	1,37	1,54
800	1,45	1,41	1,45	1,46	1,45	1,40	1,53
1000	1,47	1,44	1,42	1,41	1,41	1,48	1,52
1250	1,40	1,40	1,41	1,40	1,42	1,37	1,50
1600	1,26	1,23	1,23	1,22	1,21	1,25	1,28
2000	1,30	1,33	1,33	1,30	1,34	1,33	1,44
2500	1,41	1,43	1,45	1,39	1,42	1,43	1,38
3150	1,33	1,32	1,29	1,26	1,30	1,30	1,30
4000	1,09	1,05	1,06	1,07	1,06	1,07	1,05
5000	1,03	1,03	1,01	1,04	1,04	1,00	1,05
6300	0,85	0,86	0,85	0,84	0,85	0,85	0,82
8000	0,71	0,69	0,70	0,68	0,71	0,69	0,72
10000	0,55	0,55	0,54	0,56	0,56	0,56	0,57

Annex C – M10

C.1 - B/N measurement (anthropic noise)

Receivers positions	1	2	3	4	5	6	7	8	9	10	11	12
Band [Hz]	LZeq [dB]											
6,3	46,7	47,7	47,2	44,0	47,0	44,8	43,5	45,7	43,2	46,0	44,8	49,2
8	45,2	41,8	40,1	40,1	43,0	43,2	46,1	45,2	45,6	45,0	46,8	45,7
10	59,9	60,0	54,1	46,8	44,9	54,6	59,4	57,2	61,4	63,7	61,9	62,8
12,5	62,8	64,1	58,1	52,6	49,8	59,2	64,1	61,8	65,9	68,1	66,3	65,6
16	50,2	49,8	41,3	48,1	48,9	40,4	52,4	50,4	41,6	51,1	50,5	43,1
20	46,8	47,1	46,6	49,5	49,4	49,9	48,5	48,2	46,6	48,6	49,2	46,6
25	56,0	55,5	57,3	59,9	55,4	56,5	59,3	54,5	55,6	63,2	56,4	54,1
31,5	50,0	52,4	53,7	50,9	50,2	52,7	51,4	51,7	49,5	51,7	51,6	50,8
40	47,7	49,3	53,5	46,3	47,1	54,0	50,2	50,6	47,9	49,1	49,4	46,7
50	51,1	51,4	48,0	50,3	51,5	49,7	51,1	49,4	51,2	53,0	52,3	49,7
63	50,3	50,4	50,0	51,9	50,3	50,3	50,4	50,9	51,5	50,4	50,3	49,8
80	51,9	51,1	50,0	51,1	49,5	51,1	49,1	50,8	50,8	49,1	52,5	48,9
100	51,3	49,4	51,9	51,8	51,2	51,8	51,0	51,0	49,6	51,8	52,0	47,8
125	47,3	47,5	49,6	50,3	51,6	53,1	50,3	47,6	47,7	48,0	48,8	44,7
160	46,3	45,3	45,7	46,5	45,2	46,3	47,2	46,9	46,3	47,0	46,3	45,4
200	44,4	47,0	46,5	46,9	46,8	47,4	48,3	46,3	47,2	47,3	47,0	47,3
250	40,4	40,5	41,8	41,7	40,4	41,7	41,4	41,7	40,7	41,3	41,6	40,0
315	39,8	40,0	42,7	42,8	39,1	42,5	40,8	40,2	40,1	39,8	40,2	40,4
400	38,7	38,4	40,5	39,9	38,6	39,1	40,2	39,4	38,9	39,2	39,3	37,4
500	37,4	36,5	39,5	38,5	36,7	38,1	38,4	38,2	38,3	38,1	38,7	36,6
630	37,2	37,0	38,8	37,0	35,8	37,7	38,4	36,8	36,9	37,6	37,2	36,1
800	35,5	38,9	41,3	37,3	35,5	37,7	40,8	37,4	36,8	39,4	38,2	35,7
1000	35,5	37,4	39,5	36,3	36,7	36,9	38,9	36,4	36,2	38,3	37,0	35,7
1250	34,2	35,9	36,7	36,4	34,4	34,7	37,0	36,0	34,1	35,4	35,3	34,8
1600	32,4	34,6	35,6	36,3	32,7	33,8	36,2	33,9	32,9	33,7	33,5	34,5
2000	33,0	32,5	33,6	33,8	32,2	32,7	34,5	32,5	32,9	33,1	32,2	31,9
2500	32,1	32,2	33,1	33,6	31,7	31,9	33,3	32,0	32,6	33,1	31,8	31,1
3150	28,2	29,0	30,0	31,7	28,2	29,0	30,9	28,5	29,5	29,9	29,1	28,5
4000	27,1	27,4	29,0	31,1	27,1	27,9	29,6	28,0	28,4	28,6	28,2	27,8
5000	26,5	26,8	27,7	29,1	27,1	27,9	28,5	27,6	28,3	27,9	27,7	27,1
6300	25,2	24,3	25,5	25,8	24,2	25,2	26,5	25,9	26,4	26,1	26,0	25,0
8000	21,8	20,1	22,1	22,1	20,0	20,8	22,6	21,9	23,3	23,6	23,5	21,8
10000	19,0	18,6	19,6	19,1	18,7	19,1	20,0	19,3	20,0	19,9	19,7	19,8
12500	18,7	18,5	18,7	18,6	18,6	18,9	19,0	18,8	19,1	18,9	18,9	18,9
16000	19,5	19,4	19,7	19,5	19,6	19,8	19,7	19,7	19,9	19,7	19,6	19,6
20000	20,6	20,5	20,6	20,8	20,6	20,6	20,7	20,6	20,7	20,6	20,6	20,5

C.2 - Reverberation Time Measurement

source-receiver position	A-1		A-6		A-11		B-1		B-6		B-11		
	n. measurement	1	2	1	2	1	2	1	2	1	2	1	2
Band [Hz]	RT60(T20) [s]	RT60(T20) [s]	RT60(T20) [s]	RT60(T20) [s]	RT60(T20) [s]	RT60(T20) [s]	RT60(T20) [s]	RT60(T20) [s]	RT60(T20) [s]	RT60(T20) [s]	RT60(T20) [s]	RT60(T20) [s]	RT60(T20) [s]
50	--	--	--	--	--	--	--	--	--	--	--	--	--
63	--	--	--	--	--	--	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--	--	--	--	--	--	--
100	--	--	--	--	--	--	--	--	--	--	--	--	--
125	2,03	--	--	--	--	--	--	2,00	2,12	1,87	--	--	--
160	1,92	1,83	2,15	1,78	1,78	1,98	1,96	1,84	2,13	2,01	2,06	2,01	
200	1,83	1,88	2,76	2,65	2,12	1,97	2,17	2,00	2,04	2,06	1,90	1,87	
250	2,26	2,25	2,51	2,29	2,33	2,38	2,22	2,41	2,21	2,14	1,99	1,92	
315	2,51	2,52	2,26	2,31	2,38	2,50	2,26	2,36	2,26	2,26	2,49	2,58	
400	2,10	2,07	2,34	2,26	2,60	2,77	2,41	2,46	2,35	2,36	2,40	2,36	
500	2,33	2,42	2,21	2,23	2,43	2,35	2,25	2,32	2,15	2,10	2,15	2,24	
630	2,33	2,26	2,37	2,38	2,31	2,28	2,47	2,29	2,30	2,28	2,39	2,42	
800	2,64	2,50	2,55	2,62	2,55	2,55	2,52	2,62	2,57	2,51	2,33	2,53	
1000	2,57	2,38	2,52	2,48	2,47	2,61	2,58	2,58	2,28	2,42	2,47	2,40	
1250	2,68	2,55	2,64	2,66	2,69	2,70	2,80	2,80	2,79	2,62	2,73	2,70	
1600	2,62	2,51	2,76	2,75	2,53	2,72	2,74	2,66	2,75	2,70	2,64	2,59	
2000	2,52	2,50	2,58	2,64	2,73	2,62	2,70	2,43	2,61	2,63	2,54	2,62	
2500	2,31	2,32	2,43	2,34	2,33	2,26	2,34	2,42	2,43	2,37	2,46	2,44	
3150	2,09	1,92	2,15	2,14	2,14	2,08	2,14	2,08	2,09	2,08	2,00	2,11	
4000	1,72	1,82	1,83	1,85	1,82	1,89	1,78	1,82	1,73	1,78	1,80	1,81	
5000	1,41	1,48	1,50	1,52	1,49	1,50	1,49	1,43	1,43	1,42	1,45	1,48	
6300	1,09	1,08	1,19	1,19	1,14	1,14	1,17	1,16	1,15	1,13	1,10	1,05	
8000	0,81	0,78	0,85	0,86	0,87	0,86	0,86	0,87	0,88	0,84	0,85	0,85	
10000	0,59	0,58	0,65	0,67	0,63	0,66	0,65	0,37	0,64	0,44	0,61	0,65	

C.3 - Reverberation time with SPPS and TCR methods with $\alpha_{M10 \text{ lit}}$

source-receiver positions	RT SPPS code						RT TCR code
	A-1	A-6	A-11	B-1	B-6	B-11	
Band [Hz]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]
50	--	--	--	--	--	--	--
63	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--
100	--	--	--	--	--	--	--
125	2,28	2,32	2,30	2,25	2,25	2,29	2,01
160	2,32	2,28	2,33	2,30	2,24	2,35	2,00
200	2,28	2,25	2,36	2,35	2,36	2,35	2,06
250	2,31	2,37	2,31	2,33	2,32	2,34	2,05
315	2,37	2,32	2,32	2,28	2,36	2,30	2,04
400	3,25	3,38	3,28	3,29	3,20	3,26	2,76
500	3,19	3,23	3,17	3,23	3,29	3,23	2,74
630	3,18	3,25	3,21	3,13	3,25	3,22	2,72
800	3,51	3,45	3,41	3,43	3,40	3,44	2,87
1000	3,40	3,35	3,37	3,42	3,45	3,44	2,82
1250	3,27	3,32	3,27	3,27	3,30	3,24	2,76
1600	3,29	3,30	3,36	3,41	3,36	3,37	2,83
2000	3,25	3,14	3,23	3,10	3,12	3,22	2,69
2500	2,76	2,83	2,85	2,86	2,84	2,83	2,49
3150	2,68	2,71	2,68	2,69	2,69	2,67	2,38
4000	2,16	2,23	2,19	2,15	2,15	2,12	2,00
5000	1,71	1,66	1,68	1,72	1,75	1,70	1,63
6300	1,24	1,23	1,23	1,24	1,27	1,23	1,21
8000	0,90	0,91	0,89	0,91	0,91	0,90	0,90
10000	0,70	0,67	0,68	0,67	0,67	0,65	0,67

C.4 - Reverberation time with SPPS and TCR codes with $\alpha_{M10\text{ lit}}$ calibrated

source-receiver positions	RT SPPS code					RT TCR code	
	A-1	A-6	A-11	B-1	B-6	B-11	
Band [Hz]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]
50	--	--	--	--	--	--	--
63	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--
100	--	--	--	--	--	--	--
125	2,12	2,13	2,17	2,13	2,09	2,15	2,01
160	1,94	1,99	1,97	1,97	1,95	1,98	2,00
200	2,12	2,13	2,14	2,12	2,10	2,13	2,06
250	2,29	2,27	2,34	2,34	2,33	2,25	2,26
315	2,32	2,37	2,31	2,36	2,45	2,31	2,41
400	2,44	2,48	2,47	2,51	2,42	2,40	2,47
500	2,28	2,28	2,22	2,27	2,36	2,29	2,24
630	2,41	2,42	2,43	2,46	2,43	2,43	2,43
800	2,59	2,61	2,57	2,54	2,64	2,60	2,51
1000	2,52	2,59	2,51	2,48	2,54	2,54	2,48
1250	2,68	2,71	2,72	2,75	2,74	2,68	2,76
1600	2,73	2,78	2,79	2,77	2,78	2,75	2,74
2000	2,62	2,64	2,62	2,70	2,59	2,62	2,69
2500	2,40	2,42	2,41	2,46	2,36	2,39	2,41
3150	2,14	2,19	2,19	2,23	2,22	2,20	2,09
4000	1,83	1,85	1,81	1,85	1,81	1,82	1,79
5000	1,49	1,49	1,50	1,48	1,46	1,45	1,48
6300	1,18	1,15	1,13	1,14	1,14	1,16	1,14
8000	0,88	0,88	0,85	0,86	0,86	0,88	0,85
10000	0,62	0,62	0,61	0,61	0,60	0,60	0,60

C.5 - Reverberation time with SPPS and TCR codes with $\alpha_{M10 \text{ avg}}$

source-receiver positions	RT SPPS code						RT TCR code
	A-1	A-6	A-11	B-1	B-6	B-11	
Band [Hz]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]
50	--	--	--	--	--	--	--
63	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--
100	--	--	--	--	--	--	--
125	2,49	2,42	2,36	2,53	2,42	2,38	1,99
160	2,38	2,41	2,41	2,46	2,41	2,48	1,99
200	2,69	2,65	2,67	2,67	2,65	2,66	2,20
250	2,66	2,67	2,67	2,75	2,67	2,76	2,19
315	2,89	2,87	2,88	2,82	2,87	2,89	2,44
400	3,00	2,90	2,90	2,90	2,90	2,81	2,43
500	2,87	2,84	2,88	2,86	2,84	2,87	2,41
630	2,80	2,82	2,79	2,95	2,82	2,84	2,40
800	3,08	3,11	3,12	3,05	3,11	3,25	2,69
1000	2,97	3,00	3,02	3,05	3,00	2,99	2,65
1250	2,98	3,04	3,03	3,01	3,04	2,90	2,60
1600	3,16	3,14	3,16	3,13	3,14	3,16	2,87
2000	3,03	2,96	3,02	2,92	2,96	2,99	2,72
2500	2,76	2,73	2,77	2,70	2,73	2,68	2,51
3150	2,19	2,14	2,11	2,17	2,14	2,18	2,01
4000	1,98	1,96	2,02	1,99	1,96	1,95	1,90
5000	1,48	1,49	1,51	1,47	1,49	1,46	1,45
6300	1,13	1,17	1,17	1,14	1,17	1,17	1,15
8000	0,87	0,85	0,87	0,86	0,85	0,87	0,87
10000	0,59	0,59	0,62	0,58	0,59	0,59	0,59

C.6 – Reverberation time with SPPS and TCR codes with $\alpha_{M10 \text{ avg}}$ calibrated

source-receiver positions	RT SPPS code					RT TCR code	
	A-1	A-6	A-11	B-1	B-6	B-11	
Band [Hz]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]	T20 [s]
50	--	--	--	--	--	--	--
63	--	--	--	--	--	--	--
80	--	--	--	--	--	--	--
100	--	--	--	--	--	--	--
125	2,05	2,09	2,07	2,01	2,11	2,07	1,99
160	2,07	2,02	2,09	2,02	2,07	2,08	1,99
200	2,04	2,02	2,09	1,98	2,04	2,01	1,98
250	2,36	2,47	2,33	2,43	2,35	2,43	2,45
315	2,42	2,40	2,42	2,38	2,37	2,42	2,44
400	2,37	2,35	2,34	2,34	2,42	2,48	2,43
500	2,16	2,13	2,19	2,17	2,15	2,18	2,15
630	2,30	2,33	2,39	2,30	2,31	2,38	2,40
800	2,54	2,50	2,49	2,50	2,48	2,43	2,37
1000	2,47	2,43	2,50	2,52	2,43	2,50	2,34
1250	3,04	3,01	2,98	2,95	2,95	2,94	2,98
1600	2,54	2,56	2,55	2,57	2,57	2,62	2,51
2000	2,70	2,74	2,68	2,68	2,64	2,73	2,39
2500	2,19	2,09	2,19	2,30	2,24	2,21	2,23
3150	2,23	2,20	2,14	2,15	2,14	2,15	2,24
4000	1,68	1,65	1,69	1,73	1,75	1,65	1,74
5000	1,50	1,44	1,50	1,48	1,50	1,47	1,45
6300	1,16	1,18	1,16	1,15	1,18	1,17	1,15
8000	0,84	0,83	0,84	0,84	0,83	0,83	0,83
10000	0,62	0,61	0,60	0,60	0,59	0,61	0,61

Attachments

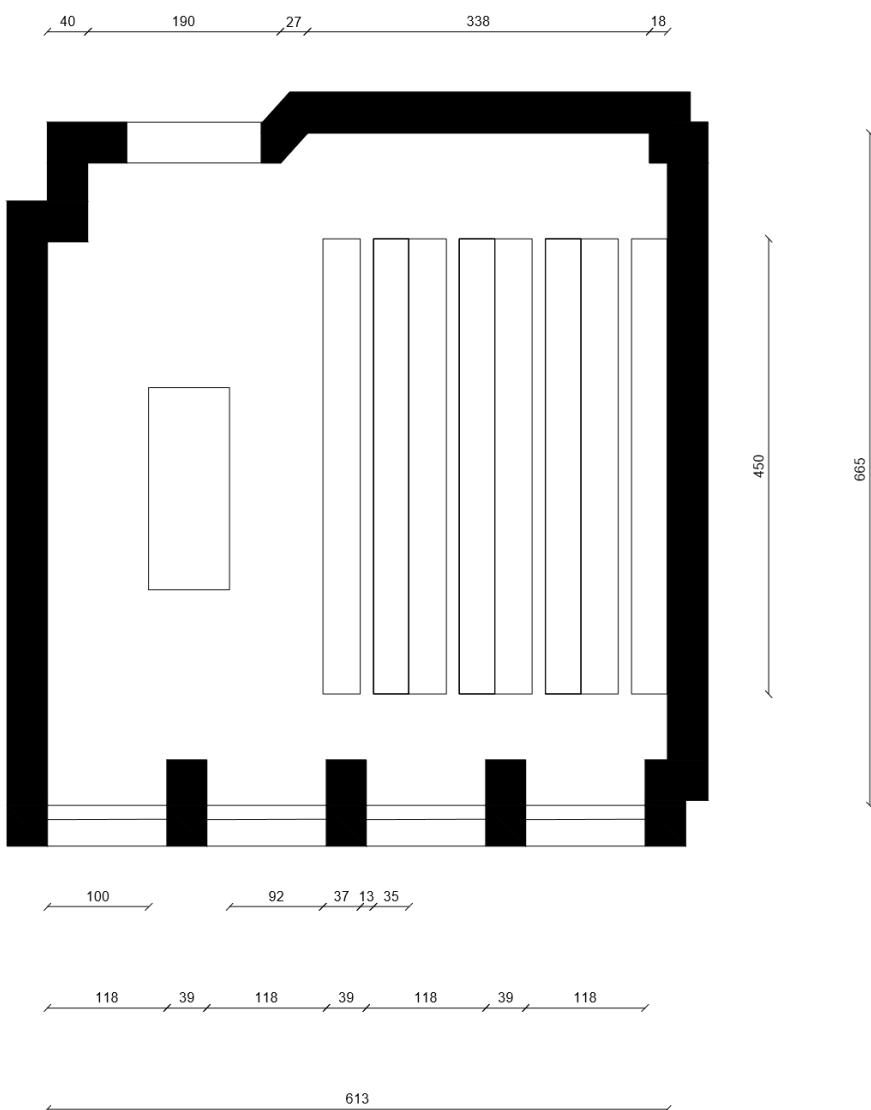
Attachment 1 – ΔApers from UNI 11532-2

	Description	Frequency [Hz]					
		125	250	500	1000	2000	4000
0	Individual of a group, standing, 1 every 6 m ² , typical minimum	0.05	0.10	0.20	0.35	0.50	0.65
1	Individual of a group, standing, 1 every 6 m ² , typical maximum	0.12	0.45	0.80	1.20	1.30	1.40
2	Person sitting on a non-upholstered chair	0.15	0.30	0.40	0.45	0.55	0.55
3	Person sitting on slightly upholstered chair	0.10	0.15	0.20	0.25	0.25	0.25
4	Person sitting on highly upholstered chair	0.05	0.05	0.05	0.10	0.10	0.15
5	Kindergarten child	0.05	0.10	0.15	0.20	0.30	0.25
6	Primary school student (up to 11 years old) sitting at the table	0.05	0.10	0.20	0.35	0.40	0.45
7	Secondary school student sitting at the table	0.10	0.15	0.35	0.50	0.50	0.55
8	0.5 m ² /person sitting on wooden chair	0.12	0.2	0.39	0.49	0.48	0.4
9	0.1 m ² /person sitting on wooden chair	0.18	0.26	0.55	0.68	0.78	0.78
10	6 m ² /person, sitting	0.12	0.18	0.35	0.56	0.68	0.74
11	6 m ² /person, standing	0.12	0.19	0.42	0.66	0.85	0.94
12	Non-occupied wooden folding chair	0.02	0.02	0.02	0.04	0.04	0.03
13	Single upholstered chair with fabric cover	0.15	0.25	0.30	0.35	0.40	0.40
14	Single upholstered chair with leather upholstery	0.05	0.15	0.20	0.10	0.03	0.03
15	Folding upholstered theatre chair	0.25	0.30	0.30	0.30	0.30	0.30
16	Musician with instrument: 1.1 m ² /person	0.16	0.42	0.87	1.07	1.04	0.94
17	Musician with instrument: 2.3 m ² /person	0.03	0.13	0.43	0.70	0.85	0.99
18	Singer < 0.5 m ² /person	0.15	0.25	0.40	0.50	0.60	0.60
19	Students in a classroom at wooden tables 3 m ² /person	0.05	0.33	0.43	0.32	0.38	0.37
20	Kindergarten children, sitting 2 m ² /person	-	0.14	0.17	0.20	0.30	0.30

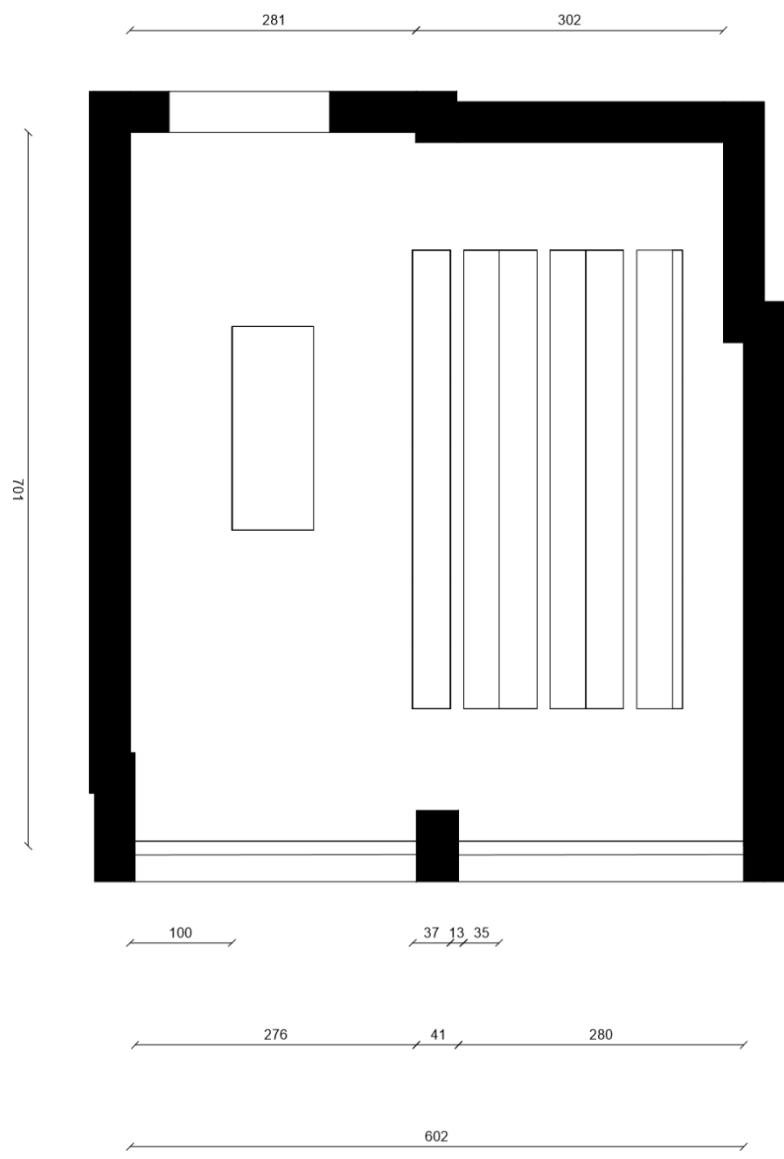
Attachment 2 – STI/STIPA evaluation IEC EN 60268-16

Category	STI STIPA	Type of message information	Examples of typical uses (for natural or reproduced voice)	Comment
A+	> 0,76	--	Recording studios	Excellent intelligibility but rarely achievable in most environments
A	0,74	Complex messages, unfamiliar words	Theatres, speech auditoria, parliaments, courts, Assistive Hearing System	High speech intelligibility
B	0,70	Complex messages, unfamiliar words	Theatres, speech auditoria, parliaments, courts	High speech intelligibility
C	0,66	Complex messages, unfamiliar words	Lecture theatres, classrooms, concert halls	Good speech intelligibility
D	0,62	Complex messages, familiar context	Concert halls, modern churches	High quality for PA systems
F	0,54	Complex messages, familiar context	PA systems in shopping malls, public buildings' offices, VA systems	Good quality PA systems
G	0,50	Complex messages, familiar context	Shopping malls, public buildings' offices, VA systems	Target value for VA systems
H	0,46	Simple messages, familiar context	VA and PA systems in difficult acoustic environments	Normal lower limit for VA systems
I	0,42	Simple messages, familiar context	VA and PA systems in very difficult spaces	--
J	0,38	--	Not suitable for PA systems	--
U	< 0,36	--	Not suitable for PA systems	--
These values should be regarded as minimum target values				

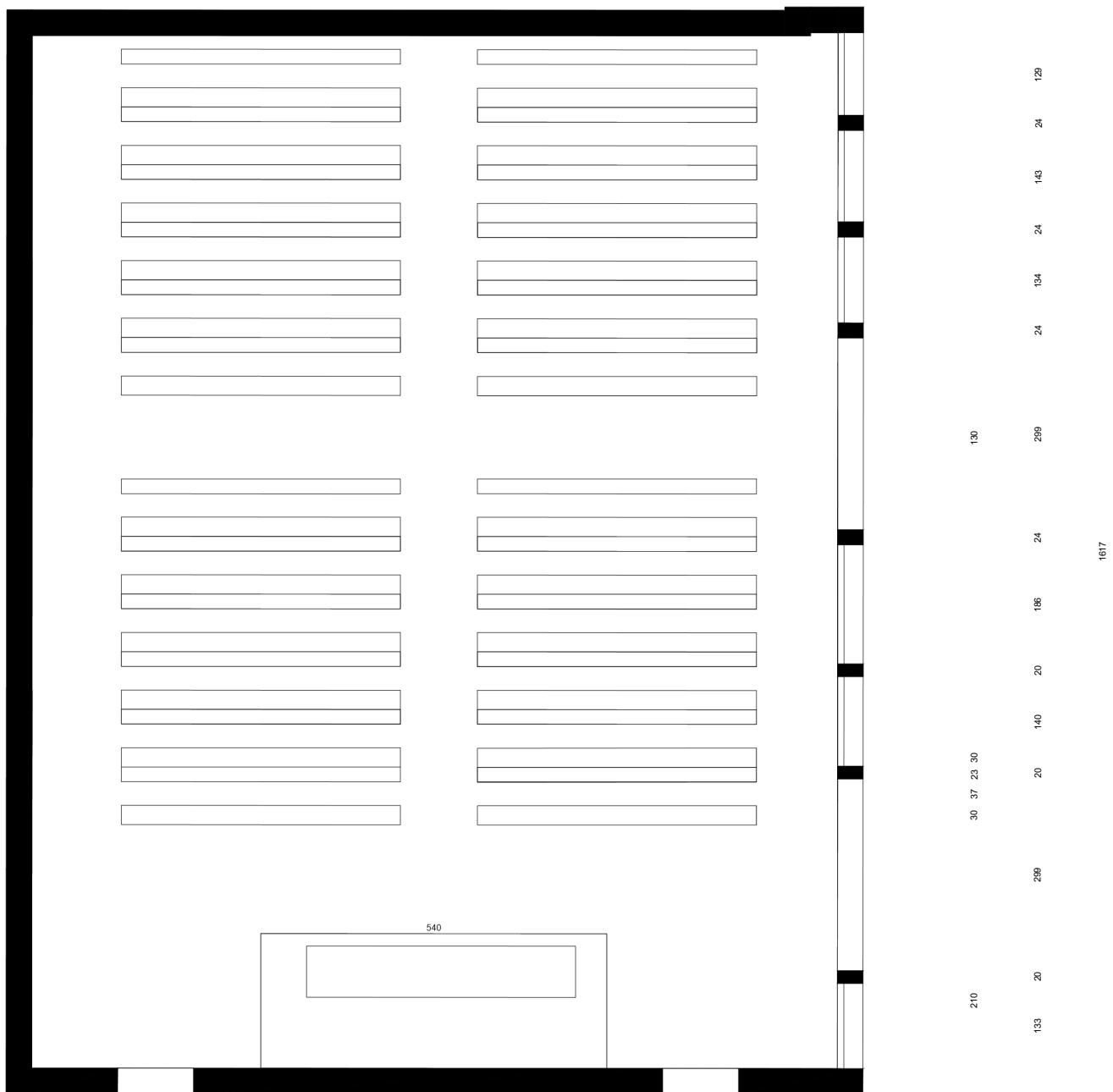
Attachment 3 - M5



Attachment 4 - M6



Attachment 5 - M10



References

- “Sistemi di segnalazione sonora e vocale – dalla progettazione al collaudo”, A. Tombolato
- “STIPA: una tecnica innovativa per la valutazione dell’intellibilità del parlato in ambienti chiusi”, F. Bertellino
- I-SIMPA Documentation, Release 1.3.4, Picault J.

Standards

- D.M. 3.08.2015: “Approvazione di norme tecniche di prevenzione incendi, ai sensi dell’articolo 15 del decreto legislativo 8 marzo 2016, n. 139”
- UNI EN ISO 7731:2009: “Ergonomics-danger signals for public and work areas-Auditory danger signals”
- ISO 8201: “Acoustics – Audible emergency evacuation signal”
- UNI ISO 7240-19: “Fire detection and alarm system: design, installation, commissioning and service of sound system for emergency purposes”
- ISO EN 3382-2: “Acoustics – Measurement of room acoustic parameter. Part 2: Reverberation time in ordinary rooms”
- UNI EN ISO 9921:2004 “Ergonomics, Assessment of verbal communication”
- ISO 8210:1987: “Acoustics – Audible emergency evacuation signal”
- ISO EN 3382-3: “Acoustics – Measurement of room acoustic parameter. Part 3: Open plan offices”
- UNI 11532-1: “Internal acoustical characteristics of confined spaces – Design methods and evaluation techniques – Part 1: General requirements”
- ISO 354: “Acoustics – Measurement of sound absorption in a reverberation room”
- ISO 9613-1: “Acoustics- Attenuation of sound during propagation outdoor, Part 1: Calculation of the absorption of sound by atmosphere”
- IEC 60268-16:2011 “Sound system equipment - Objective rating of speech intelligibility by speech transmission index”.

- UNI 11531-1: “Internal acoustical characteristics of confined spaces - Design methods and evaluation techniques – Part 1: General requirements”
- UNI 11532-2: “Internal acoustical characteristics of confined spaces - Design methods and evaluation techniques – Part 2: Educational sector”

Websites

- https://mypages.iit.edu/~muehleisen/acs_demos/reverb_demo/classroom.html
- <https://www.acoustic-supplies.com/absorption-coefficient-chart/>
- <https://i-simpa.ifsttar.fr/>
- <https://www.nti-audio.com/en/>