SURFACE ABSORPTION COEFFICIENT MEASUREMENT

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Abstract – *The present paper details the procedure of the design, construction and measurement of a resonant absorber. The measurement methodology corresponds to the guidelines established by ISO 354 standard. The design of the resonator is based on the theory studied and the requirements of the standard, in order to obtain a test specimen appropriate for the measurement. The location used was a classroom with reverberant conditions, at UNTREF's Annex.*

1.

2. INTRODUCTION

In the present paper, the design and construction of resonant absorbers is explained. Also, the results of the measurements according to ISO 354 standard are presented and analyzed. Measurements were carried out in a classroom at UNTREF.

In order to achieve low to mid frequencies control in listening rooms, the resonant absorbers are used due to their advantages, since it's difficult to obtain this with porous absorbers materials. There are two principal types of resonant absorbers: the Helmholtz absorber and the membrane or panel absorber.

The reverberant room`s volume, as explained at item 2, shall be larger than 150 m^3 according to the international standard ISO 354. However, it was not possible to measure at this conditions because of a lack of resources. The room used is not exactly a reverberant room, but its acoustical characteristics are similar to it. The volume of the room is 96 m^3. In order to adapt the test specimen to the dimensions of the room, the lower and upper limit of its area required at the international standard used, were multiplied by the factor presented at equation 2. The test specimen was built so that its measures were adapted to the measuring room available at the university.

However, it is necessary to clear out that the room does not applies to the standard. Although the specimen was adapted, the standard requirement of multiplying the lower and upper limit of the specimen permitted area (item 2.2), is for rooms larger than 200 m^3, it does not applies for rooms smaller than 200 m^3.

This paper is organized as it follows: first, the theory of resonant absorbers is introduced, then the guidelines of ISO 354 standard are presented, and then the design and construction of a Helmholtz resonator is detailed. The measurement procedure is explained, and then the results and interpretation of them are presented.

3. THEORETICAL BACKGROUND

2.1 Resonant absorbers

Resonant absorbers are used for treating low to mid frequencies. They consist in a mass spring system with damping, and provides absorption at the resonant frequency of the system studied [1]. The mass of the system can be represented by the air in the neck of the resonator's holes, in the case of a Helmholtz resonators. The air cavity represents the spring, and the damping is provided by the porous material located on the inside of the resonator.

The most common resonant absorbers used are the membrane or panel absorber and the Helmholtz resonator.

In order to obtain the losses on specific frequencies, the porous material must be located where the particle velocity is large. In the case of a Helmholtz resonator, the porous material should be located in the neck. In panel absorbers, it should be behind the membrane.

As it has been mentioned on the introduction section, the present paper explains the design and construction of a Helmholtz resonator, so its principal characteristics must be detailed.

2.1.1 Helmholtz resonator

In the Helmholtz resonator, one of the surfaces is perforated and, as a consequence, divided into individual cells with a distance D between them. According to the theory, the spacing between the perforations must be large compared to the diameter of the holes. Besides, it is expected that the thickness of the sheet and the radius of the holes are much smaller than the wavelength of the sound in air. Then, the resonant frequency can be calculated.

Instead of using holes, the slots can be an alternative for Helmholtz resonators, since its construction could be easier. By making the slots or using parallel wood slats, the orifice can be made.

In section 3 (Design and construction), the equations used for the resonators constructed and measured in the present work are detailed.

2.2 Guidelines of the ISO 354

2.2.1 Measurement conditions

According to ISO 354 standard, the volume of the room used for the measurement must be at least 150 m^3.In case of new constructions it is recommended a volume of at least 200 m^3[2]..

The condition for the shape of the reverberation room is given by equation 1.

$$l_{max} = 1.9\,V^{\frac{1}{3}} \tag{1}$$

where

l_{max} is lenght of the longest line which fits the boundary of the room.

V is Volume of the room

The equivalent sound absorption area, in one third octave bands, must not exceed the values detailed in Annex 1.

In case that the volume differs of 200 m^3, the values given at table in Annex 1 must be multiplied by equation 2:

$$\left(\frac{V}{200}\right)^{2/3} \tag{2}$$

2.2.2 Test Specimen conditions

ISO 354 standard specifies that the area of the test specimen must be between 10 m^2 and 12 m^2. For room volumes that are greater than $200 m^3$, the value of the upper limit of the test specimen must be multiplied by the factor given in equation 2.

The shape of the test specimen must be rectangular, and the ratio of width to length must be between 0,7 and 1.

2.3 Measurement

ISO 354 standard explains that the microphones must be located in the room at three different positions at least. The minimum number of sound source positions must be two. Besides, the number of microphones positions times the number of sound sources positions must be 12.

The microphones must be omni directionals and they have to be located at 1 meter from any surface, 2 meters from the sound source. Besides, the distance between the microphones must be at least 1,5 meters.

The different source positions must be located at a distance of 3 meters between them.

For the present paper an exponential sine sweep was used for the excitation of the room. The signal was generated with the Aurora plug-in, and reproduced with an omnidirectional sound source. Although this type of signal it is not mentioned in the standard, the methodology used corresponds to the integrated impulse response method. The indirect impulse response method describes the use of tone sweeps.

The procedure for the integration of the impulse response consists in generate de decay curve by a backward integration of the squared impulse response, for each frequency band.

With no background noise, the integration would start at the end of the impulse response (t →∞), and then continue to the beginning of the squared impulse response. In equation 3, the decay as a function of time is observed:

$$E(t) = \int_{0}^{inf} p^2(\tau)d\tau - \int_{0}^{t} p^2(\tau)d\tau = \int_{inf}^{t} p^2(\tau)d(-\tau) \tag{3}$$

where

$E(t)$ is the backward integrated squared impulse response;

$p(\tau)$ is the sound pressure impulse response.

2.4 Calculation

Equation 4 defines the equivalent sound absorption area of the empty reverberation room (A_1, in m^2):

$$A_1 = \frac{55{,}3}{cT_1} - 4Vm_1 \quad (4)$$

Where:

c is the speed of sound in air [m/s];

T_1 is the reverberation time of the empty room [s];

m_1 is the power attenuation coefficient, according to ISO 9613-1 standard [3].

Equation 5 is used to calculate the equivalent sound absorption area of the reverberant room with the test specimen (A_2):

$$A_2 = \frac{55{,}3}{cT_2} - 4Vm_2 \quad (5)$$

Where:

T_2 is the reverberation time of the empty reverberant room;

m_2 is the power attenuation coefficient

Then, using equations 4 and 5, it is possible to obtain the equivalent sound absorption area of the test specimen, described in equation 6:

$$A_t = A_2 - A_1 \quad (6)$$

Then, the absorption coefficient was calculated by equation 7:

$$\alpha = \frac{A1}{S} \quad (7)$$

Being S the surface of the test specimen.

4. DESIGN AND CONSTRUCTION

A Helmholtz resonator was constructed. The built methodology was based on the typically Helmholtz resonator with multiple holes. The frequency of this resonator type responds to the Equation 7.

$$f = \frac{c}{2\,.\,\pi}.\sqrt{\frac{p}{d.\left(D + 1{,}6\,.\,r_{eq}\right)}} \quad (8)$$

Where: d = height of the resonator in meters

D = throat thickness of the slots in meters

r_{eq}= equivalent ratio of the total holed surface in meters

p = percentage of the holes

f = resonance frequency in Hz

Figure 1 shows the structure, dimensions and named parts of the resonator. All lengths are in centimeters. The resonator consist of a wood rectangle as lower cap, wood boards as top cover as shows the Figure 1, and wooden slots as side structure. Inside the resonator is filled with foam, to improve the absorption coefficient. Between the boards are free-wood slots whose function is the same as for the holes, like volumetric air mass.

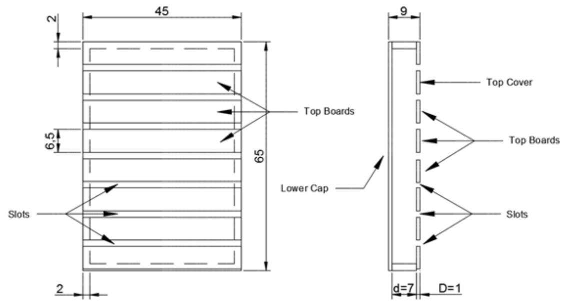


Figure 1: dimensions and names of the slot Helmholtz resonator

With the dimension on Figure 1, the frequency without foam was calculated. The value of the resonance frequency is 203 Hz. But, with foam the Q (selectivity factor) of the system on resonance is lower and the resonance frequency slightly increases. The equivalent ratio was calculated as the radius required to obtain a circle whose surface is the same as the surface of the slots. The number “1.6” which is multiplied the equivalent radio arises from the extension of volumetric air mass on the typical Helmholtz resonator’s hole. Thus this extension cannot be exactly the same on the Helmholtz resonator’s slots. This means that the frequency of the resonator can be higher.

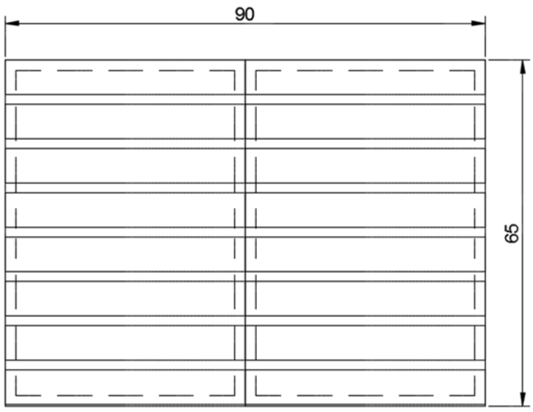
For another consideration about the extension of volumetric air mass, the Equation 8 show the new calculus of the resonance frequency, where the equivalent ratio is multiplied by the half. In this new case, the resonance frequency value is 281 Hz.

$$f = \frac{c}{2\,.\,\pi}.\sqrt{\frac{p}{d.\left(D + 0{,}8\,.\,r_{eq}\right)}} \quad (9)$$

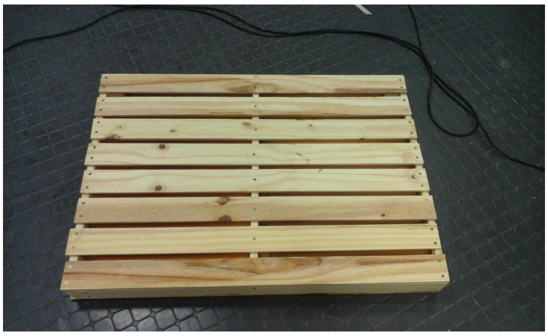
To make easier and faster the manufacture of the Slot Helmholtz Resonator three combinations of resonators was performed. Two combinations of two resonators and one combination of four resonators were made. These combinations were performed to improve the measurement of the absorption coefficient, due the standard implies a few configuration of the resonators placement.

The Figure 2-a shows the first combination of two resonators and Figure 2-b shows a photograph of it. The Figure 3-a shows the second combination of four resonators and Figure 3-b shows a photograph of it.

On the occasion of improve the estimation of the absorption coefficient, a simulation was made with an Excel Simulator Porous Absorber Calculator V1.59. The results of this software are included on Annex 2.

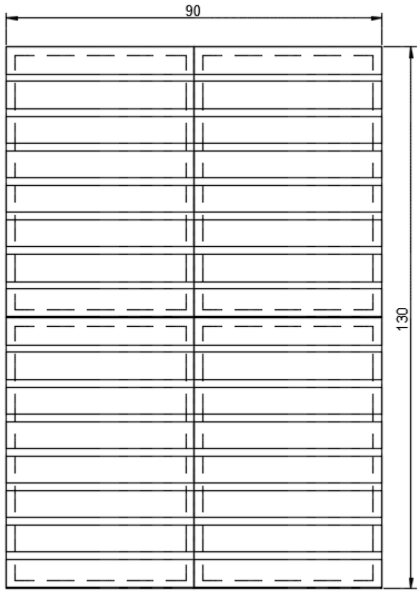


(a)



(b)

Figure 2: combination of two slot Helmholtz resonators: a. the dimension of it; b. photograph



(a)

(b)

Figure 3: combination of four slot Helmholtz resonators: a. the dimension of it; b. photograph

5. MEASUREMENT

4.1 Equipment and software

The following equipment was used for the measurement:

• Sound Level Meter Svantek SVAN 959, with extension cable

- Earthworks Microphones M50
- Calibrator Svantek SV-30-A
- Outline Globe Source Radiator (dodecahedron), and Global Subwoofer Source (subwoofer).
- Laser rangefinder Bosch DLE 70
- Tascam US-4x4
- Laptop ASUS i7

Also, the following software was used:

- Adobe Audition 3.0 with Aurora plug-in
- SVANPC++
- Smaart 6
- Audacity 2.0.5
- Excel Simulator: Porous Absorber Calculator V1.59

4.2 Calibration

Before and after the background noise measurement, the sound level meter was calibrated. A Svantek calibrator was used, with a frequency of 1 KHz and a level of 94 dB. The values corresponding to “Cal Factor” were obtained. These values, that are detailed in table 1, are used in the uncertainty section.

Table 1: Sound level meter calibration factors

Initial	Final
0,59	0,62

To calibrate the measurement microphones, the Svantek calibrator and an adapter were used. The levels of the four microphones were paired using a frequency of 1 KHz, regarding the results of the calibration in the software Adobe Audition.

4.3 Room characteristics and environment

The location for the measurement was a classroom at UNTREF’s Annex. Although it is not a reverberant chamber, it is the most appropriate room available at the University, due to its reverberant characteristics. It has concrete walls and a rubber carpet on the floor.

All the desk and chairs were removed from the room before the measurement.

It is important to consider that the building is close to the train station, so the low frequency noise can affect the measurements. Besides, the day that took place the measurement, it was raining, and the sound that the rain drops produces on the roof must be taken into account.

The dimensions of the room are 5.22 meters width, 6.07 m length and 2.98 m high.

To improve the analysis of the results, the Schroeder frequency was estimated. In the Annex 5 the calculus is shown. This frequency determine an approximation of the frequency when the influence modal density is lower than the reverberation time.

The Schroeder frequency for the RT measurement, made after the average of all frequency’s RTs, was 298 Hz.

4.4 Measurement procedure

The reverberation time measurements were made. An exponential sine sweep generated with the Aurora plug-in in the software Adobe Audition was used. The characteristics of the signal can be seen in figure 4.

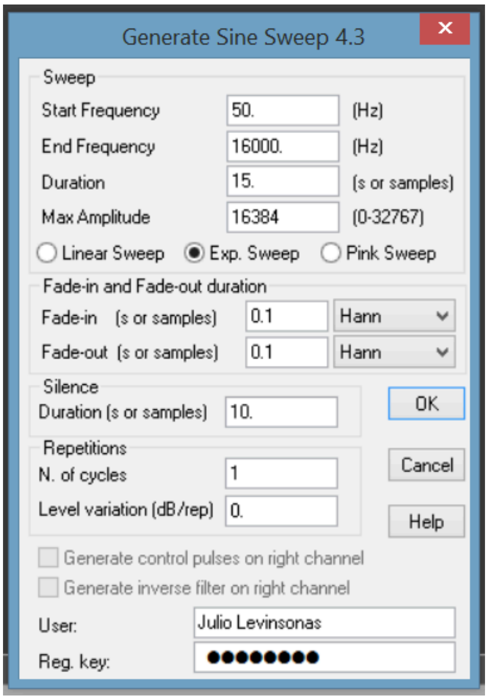


Figure 4: Exponential Sine Sweep generated with Aurora plug-in.

First, the RT of the empty room was obtained. Using 8 different microphones positions and 4 different sound source positions, the RT value was obtained.

Then, the measurement using the resonant absorbers took place. For the present paper, there were measured three different resonant absorbers configurations, and also three different surfaces. For each measurement, 8 different microphones positions and 2 sound source positions were used.

The sound source and microphone positions are detailed on table 2 and 3, respectively.

Sound source positions (in meters)

	x	y	z
Position 1 (S1)	4.20	1.16	1.66
Position 2 (S2)	4.15	5.08	1.71

Table 2: Sound source positions.

Microphones for S1 (in meters)			
Micro phone	**x**	**y**	**z**
P1	4.06	3.45	1.27
P2	1.9	2.34	1.37
P3	1.94	3.83	1.31
P4	3.66	4.9	1.72
P5	3.24	2.94	1.22
P6	1.52	1.32	1.38
P7	1.19	4.72	1.35
P8	2.74	4.67	1.61
Microphones for S2 (in meters)			
Micro phone	**x**	**y**	**z**
P1	3.11	2.88	1.02
P2	1.9	2.34	1.37
P3	1.94	3.83	1.31
P4	2.73	1.09	1.55
P5	3.56	2.75	1.33
P6	1.52	1.32	1.38
P7	1.19	4.72	1.35
P8	3.23	1	1.55

Table 3: Microphones positions.

The resonant absorbers were located at the classroom's floor, regarding that their bounds were not parallel to the walls. Three differents set ups were measured, as it can be seen on figures 5, 6 and 7.

Figure 5: First samples configuration

Figure 6: Second samples configuration.

Figure 7: Third samples configuration.

Then, three different surfaces (in m^2) were measured: the three samples together (which corresponds to the first configuration measurement, the "standard configuration", in figure 7), the larger sample and one of the smallest, and then only the larger sample. The two last resulting different surfaces can be seen on figures 10 and 11.

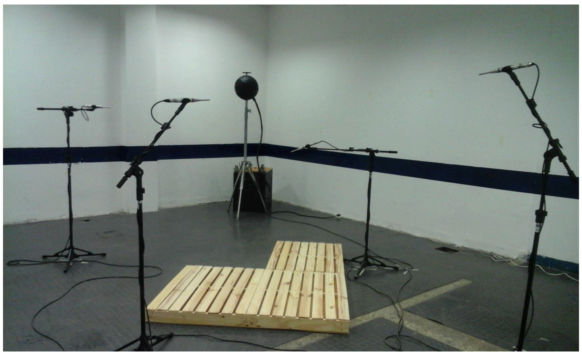


Figure 10: Second surface.

Figure 11: Third surface.

The largest sample contains 4 resonators in its interior. Each smallest sample contains 2 resonators.

The surfaces in m^2 of every configuration are detailed on table 4:

Table 4: Three different surfaces measured.

Configuration	Surface [m^2]
3 samples	2.34
2 samples	1.755
1 sample	1.17

4.5 Background noise measurement

Before starting with the RT measurements in the room, the background noise was obtained. There were made three measurements of it, using a Class 1 Sound Level Meter Svantek SVAN 959. Was made four measurements with no ponderation (Z ponderation), in slow mode, with a time integration of 1 second and repetition cycle of 10 seconds. average of four measurement was made. The results are presented on three octave band in the Annex 1.

6. RESULTS

Since the volume of the room is $94.30\ m^3$, the condition at Equation 1 is fulfilled.

The Table 1 was adapted to the volume of the room according to item 2.1. The modified values are presented at Table 5 at the Annex 1.

The objective was to adapt the specimen dimensions to the dimensions of the room. According to the standard, the area lower limit shall be $10\ m^2$ and the upper limit shall be $12\ m^2$. Both limits were multiplied by the factor described at Equation 10.

$$\left(\frac{94.3}{200}\right)^{2/3} = 0.6057 \qquad (10)$$

The results for the lower and upper limit respectively are 6.06 and $7.27\ m^2$. The test specimen built has $2.34\ m^2$ because of a lack of resources.

The results for the empty chamber are shown at Table 2 from the Annex 1.

The absorption area was calculated for every different test specimen configuration by Equation 6. The results are presented at Figure 12.

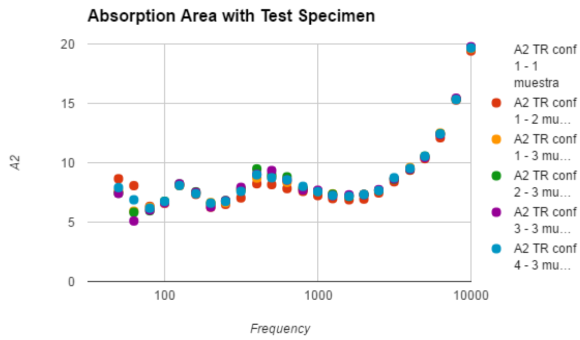


Figure 12: Absorption Area with the test specimen at different configurations.

The absorption coefficient was calculated for every different configuration by Equation 7. The results are presented at Figure 13.

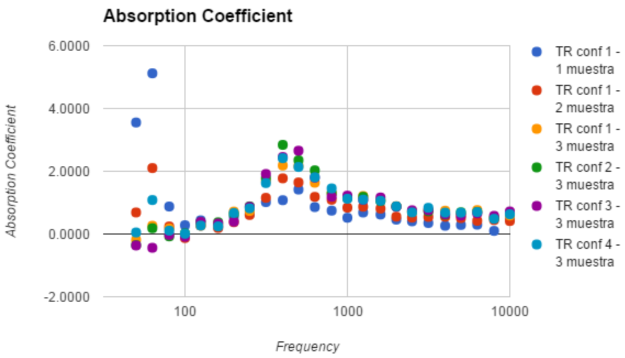


Figure 13: Absorption coefficient for every configuration.

The last results required is the standard deviation. The results are shown at Figure 14.

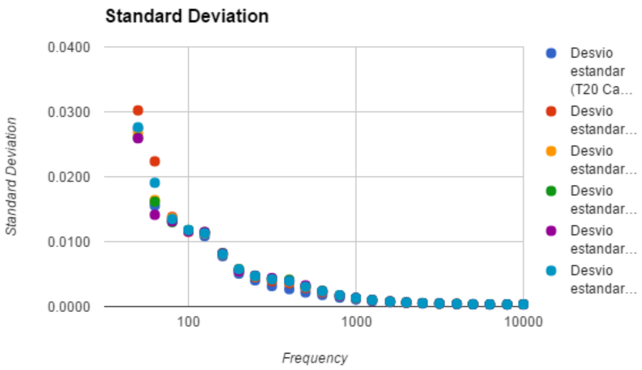


Figure 14: Standard deviation of the reverberation time measured.

6. DISCUSSION

The design of resonant absorbers was made according to the theory studied and regarding the guidelines of the standard, in order to carry out a correct measurement procedure. Several requirements described in ISO 354 standard were not accomplished, due to the resources available at the moment of the measurement:

· the room volume was 96 m^3, when the minimum required value was 150 m^3;

· the classroom used for the measurement is not a reverberant chamber, although it has reverberant characteristics;

· the area of the test specimen was 2.34 m^2, when the values required by the standard were between 10 and 12 m^3.

For further investigations, it is necessary to build more samples of the resonant absorber, to reach the minimum surface required by the standard. This way, the results will be more accurate, and it will be possible to determine if the resonators works as it was expected.

Despite the mentioned limitations, an approximate value of the absorption coefficient was obtained. Based on the results, it was impossible to determinate de influence of the resonator in low frequencies, below 80 Hz, due to the limited room volume. Nevertheless, above that frequency, a variation of the reverberation time was observed, this mean that an estimation of the coefficient was possible to make.

Add to the lack of resources on the room, the background noise due the to train station near the measurement place worsens the accuracy in low frequencies.

7. CONCLUSIONS

A Helmholtz resonant absorber was designed and built, according to the theory studied. Then, the measurements took place, using the guidelines established on the ISO 354 standard. The absorption area and absorption coefficients (for each configuration required) were calculated.

The results of the absorption area of the room are significantly greater than the maximum values permitted shown at table at the annex 1. The room does not applies for the standard ISO 354.

Despite this, the absorption coefficients values and the simulated absorption coefficients are similar. Two differences can be observed: the resonance frequency of the simulated absorption is slightly upper from the measurement resonance frequency (when the absorption coefficients are higher). But the resonance frequency of the resonator without any absorption foam, is lower than the measured one. By comparing these values it can be concluded that the measurements values are close to the real absorption coefficients of the specimen.

In the other hand, due to the high background noise on low frequencies and the room volumen below the standard ISO 354 recommendation, an interpretation of the results on low frequencies was impossible to make. The frequency that it happened are around 100 Hz, which is closed to the Schroeder Frequency estimated.

Finally, the edge effect absorption apparently doesn't have a high involve in the absorption results. Because the room's RT values ware not sufer high modifiers between differents configuration of the specimens.

For an exhaustive accuracy of absorption coefficient measurement method for specimens below the standard ISO 354 recommended, a new measurement with all the requirements of the standard is necessary. For future work, the comparison between this paper and the same specimens incide on ISO 354 requirements can be useful to determine a new method of reduced specimen's measurement.

8. REFERENCES

[1] Cox T. J., D'Antonio P. "*Acoustics Absorbers and Diffusers*". Taylor & Francis.. USA. 2009.

[2] ISO 354:2003. "*Acoustics – Measurement of sound absorption in a reverberation room*". Second edition. 2003.

[3] ISO 9613-1: 1993. "*Attenuation of sound during propagation outdoors - Part 1: Calculation of the absorption of sound by the atmosphere*". First edition. 1993.