CONTROL ROOM DESIGN

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This document describes the design of a small ambechoic control room for a recording studio, for 8 people according to the DISPO regulations of CABA, Argentina. Five different monitoring systems were installed, two for stereo productions, one for binaural audio productions, and one for 3D audio productions. Acoustic treatment and soundproofing calculations are also included. The reverberation time obtained in the different frequency bands were within the tolerances established by the AES.

Keywords: control room, ambechoic, recording studio, multichannel system

1. Introduction

The development of sound recording studios advanced from the 1920s. From the 1980s mainly, many small studios began to operate in the recording studio industry. Good recording spaces, good monitoring conditions, good sound isolation and a good working environment are basic requirements for any studio.

When stereo arrived, a new set of restrictions for the design arrived with it. The listening position became a function of the loudspeaker distances and the subtended angles between them [1]. Various styles of control rooms were developed to improve the listening position relative to these, such as LEDE (Live-End, Dead-End), RFZ (Reflection-Free Zone) and N-E (Non-Environment) design. But these have their limitations in the present for monitoring of other categories, such as surround sound.

The aim of this study is to design a control room for 8 people according to the DISPO regulations of Argentina [2], with stereo, binaural and surround monitoring systems. The studio design used is of the ambient anechoic type [3]. The design also takes into account aspects of ventilation, sound isolation and construction details.

2. State of Art

The listening position in the control room is a function of the room (its geometry and materials), the loudspeakers, and the relative distance between these and the listening spot in the room. In the late 1970s, Don Davis and Chips Davis established the concept of LEDE (*Live-End, Dead-End*) control rooms [4]. The LEDE rooms rely on some psychoacoustic criteria such as the Haas effect and the directional aspects of human hearing. Its geometry and material distribution is designed to produce a zone free of early reflections (RFZ) around the listening position. Therefore, the front half of the room is largely absorbent, and the rear half of the room is reflective and with diffusers.

In the early 1980s Tom Hidley developed a new principle for the control room designs called Non-Environment [5]. The front wall of the control room is maximally reflective, as well as the floor. The other room surfaces are made as absorbent as possible. With the monitors set flush into the front wall, it acts as a baffle extension, thus bringing the loudspeakers into something approximating an anechoic termination.

Now, a new paradigm of control rooms of recording studios based on complete low frequency absorption and high frequency diffusion is presented as a solution to optimal surround monitoring.

3. Theoretical framework

3.1 Ambechoic designs

The *ambechoic* spaces refer to the “ambient anechoic rooms”, conceptually these ambients provide a uniform acoustical environment in rooms which utilise surround systems. This concept was developed by Petrović and Dadović [3] to apply in small rooms (less than 80 m^3). The basic initial design conditions defined by them are homogenous diffusion on all surfaces above approximately 1 kHz, except the floor; and maximum possible absorption in frequencies below 250 Hz, homogenous on all surfaces except the floor. Between these limits, there is a transition zone as shown in Figure 1. Also the left-right symmetry must be taken into account throughout the design

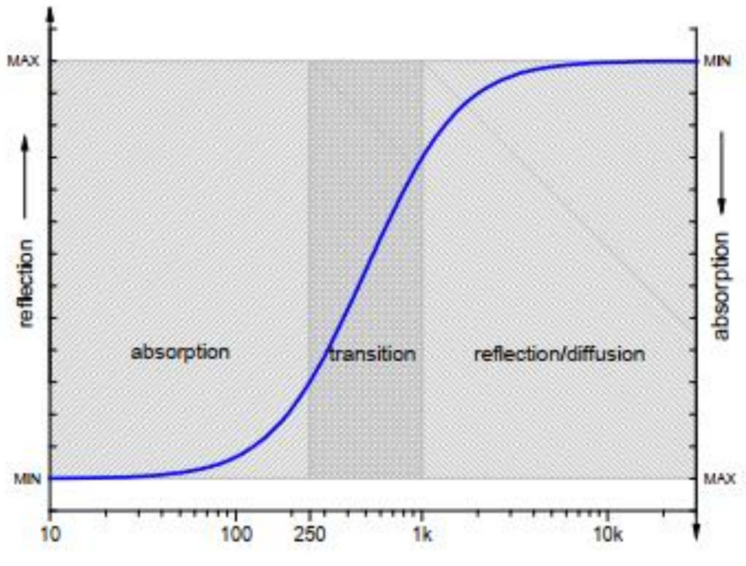

Figure 1. Initial design condition on all surfaces except the floor [3].

The low frequency absorption utilized is the same used in the non-environment design developed by Hidley and Newell [5], arranged on all room surfaces with the exception of the floor. On the internal surfaces given by the absorption limits, the diffusers are placed with enough air transparency not to diminish the efficiency of wideband absorbers behind them. Diffusers are made using Schroeder's formula, with slats separated by opening for the air.
The Energy Time Curve (ETC) must have a difference between the direct sound and the point where decay starts around 20 or 30 dB according to Massenburg's Blackbird Studio C control room [6] and MyRoom [3].

3.2 Monitoring system

Ideally, the control room monitoring system should be of high resolution, full audio bandwidth, low distortion. The monitor response depends not only on the loudspeakers. The monitor chain begins in the mixing console and ends in the control room, past through the speakers. The way that humans naturally listen is binaural, that is to say listening through the two ears. However, there is another audio interpretation of the word, and that narrowly applies to "binaural" recordings made with an anatomically correct dummy head, a mannequin, that captures the sounds arriving at each ear location so subsequently these two signals can be reproduced at each of the two ears. This is most commonly done through headphones, which offer excellent separation of the sounds at each ear, or through two loudspeakers, using a technique called acoustical crosstalk cancellation. The idea is that the listener hears what the dummy head heard.
The stereo word comes from the basic meaning of "solid, three-dimensional", now firmly entrenched as describing two-channel sound recording and reproduction. Nowadays, the stereo recordings that were made to be reproduced through two loudspeakers symmetrically arrayed in front of the listener are enjoyed through headphones by multitudes. What is heard, though, is not stereo; it is mostly inside the head spanning the distance between the ears, with the featured artist placed just behind and maybe slightly above the nose.
The multichannel sometimes is an ambiguous descriptor because it applies to two-channel stereo as well as to systems of any higher number of channels. In the mass market the preferred number of channels in this type of system is 5 plus a limited-bandwidth channel reserved for low-frequency.
Two-channel signals can be upmixed for reproduction through five or more channels, or five channels can be upmixed for reproduction through six, seven, or more. For example, in the case of dolby surround (which generates Lt+Rt composite signals), multichannel recordings are downmixed, encoded, with a specific form of upmix decoding in mind. Upmixers may also be optimized to convert standard stereo music recordings into multichannel versions (also known as "blind" upmixers) [7].

3.3 Ventilation

The ventilation of a room is directly related to the amount of particles per million of carbon dioxide (CO_2). This indicates the levels of air pollution depending on the volume of the room and number of people. The carbon dioxide concentration is a good indicator of the accumulation of exhaled aerosols [8]. The recommendations indicate the number of renewals/hour such that it avoids reaching 800 ppm (parts per million) of CO_2 concentration.The CO_2 concentration after a certain time is given by Eq. (1).

$$c = \left(\frac{q}{n\,v}\right)\left(1 - \frac{1}{e^{\,n\,t}}\right) + (c_o - c_i)\left(\frac{1}{e^{\,n\,t}}\right) + c_i \tag{1}$$

where :
c: carbon dioxide concentration in the room *(m^3/m^3).*
q: carbon dioxide supplied to the room *(m^3/h).*
n: number or renewals per hour*(1/h).*
v: volume of the room *(m^3)*.
t: time *(h).*
C_i: carbon dioxide concentration entering the vent *(m^3/m^3).*
C_o: initial carbon dioxide concentration in the room, in $t = 0$ *(m^3/m^3).*

The regulations and minimum requirements set in the annex of the code of building, Law N° 6.100 (CABA) [9], in a closed place there must be a replacement air of 2,50 m^3 per hour, per person.

3.4 Sound isolation

Noise levels within the control room must be considerably low, as it is a critical listening environment. In addition, the sound within the enclosure should not harm the neighboring enclosures.
Considering a control room as a work space, the sound level pressure must not exceed 85 dBA [10]. In turn, the Ley N° 1540 and its regulatory decree N° 740 established a level in control rooms of recording studios of 110 dBA [11], although this is not a realistic level for the environment of control rooms. The structure of the studio must present sound isolation sufficient to have a controlled interior environment of background noise, and not to contaminate the neighboring areas.
AES recommendations [12] establishes that in terms of the control room listening environments, ideally the background noise should be less than the NR10 curve.

4. Procedure

4.1 Control room design

The DISPO regulation of Argentina in the context of the SARS-CoV-2 pandemic [2], established a minimum distance between people of 2 meters. To create an environment according to these regulations for 8 people, taking into account the space occupied by furniture, and the ventilations requirements (see section 4.3), the total surface of the room is 62,9 m^2 and a height of 3,2 m.
After calculating the necessary surface, it was determined that the shape of the control room should not present parallel walls, to reduce from the first moment problems associated with acoustic modes. With this in mind, an irregular heptagon shape, perfec was adopted. The final dimensions can be seen in Figure 2. The presented shape presents perfect symmetry from the mixer engineer perspective.

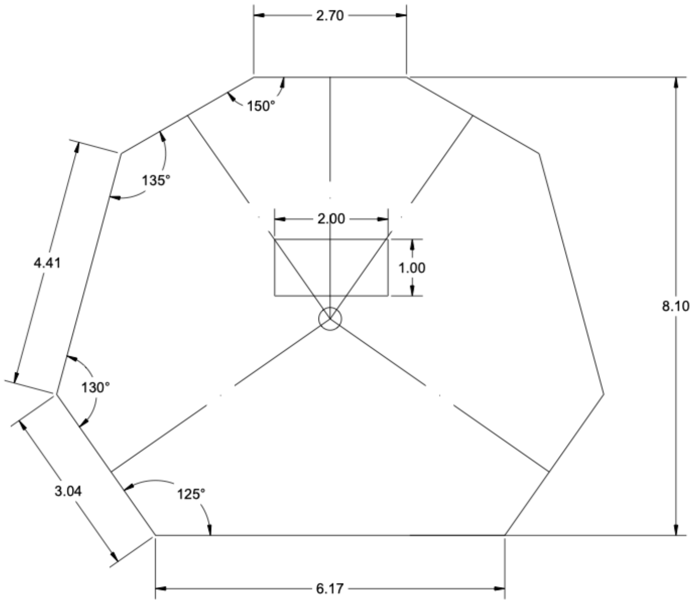

Figure 2. Control room internal shape with dimensions in meters.

The desk selected for the control room is the Halo.K Ultimate [13]. This workstation counts with antivibrant bases to place two near field monitor speakers. As this studio will get most of the mixing work done in the box (digitally within the computer), no separated racks for hardware units were needed. However, the selected desk has dual eight space rack bays to place hardware units, A/D converters, and anything that may be needed or added afterwards to the studio.

4.2 Absorption and Diffusion

The control room presented in this document is designed under the "anechoic design" guidelines, thus it counts with big amounts of absorption for the low and low-mid frequency region, and predominant diffusion in the mid-high and high frequency region. The sweet spot should be free of early reflections, eliminating the sound coloration factor associated with them. In order to accomplish this, diffusers were placed in all the walls. In Figure 3 the diffusers and absorbers distribution can be seen. This also indicates the double decoupled window of 2,0 m x 1,1 m of visual communication between control room and recording room, and the two entries that maintain the symmetry of the enclosure with their respective sound-lock to avoid loss of insulation in the openings. Figure 4 presents the same idea but seen from the side without ventilation details.
It should be noted that the minimum distance from the absorbers is 60 cm, therefore, due to the internal geometry of the enclosure, there are areas of greater thickness, and where there is greater absorption at low-frequencies.

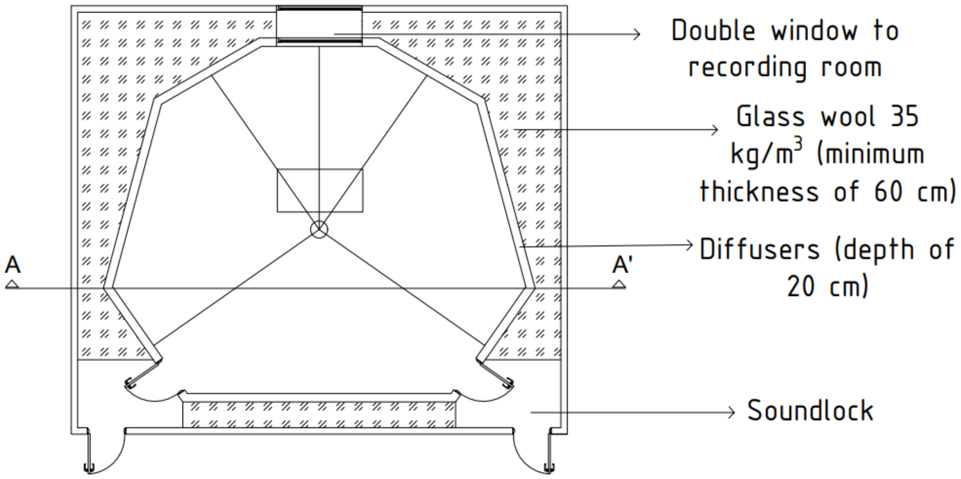

Figure 3. Diffusers and absorbers placement (hatched area).

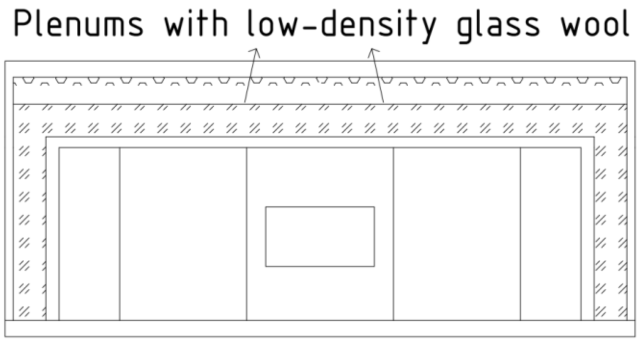

Figure 4. Horizontal cut view A-A' .

Said diffusers were designed by inventing a new 1D amplitude grating diffuser which has enough air transparency not to diminish the efficiency of the absorbers that should be placed behind them, generating a slat absorber with diffuser. This allows a link between low-frequency absorption efficient and high-frequency room liveliness.

A number sequence of 11 elements was chosen, with 1 cm of air gap between each one of the cells according to the development of Petrovic [14]. The sequence of the numerical diffuser is shown in Eq. (2) with 2 cm per each step of the numerical sequence, its ACQF value is 0,1467, which indicates a high level of randomness.

$$S = [7, 7, 8, 6, 5, 2, 1, 9, 4, 4, 5] \tag{2}$$

The maximum depth is 18 cm, therefore the minimum operating frequency is 952 Hz. The width of each cell is 2 cm, which indicates a maximum operating frequency of 8575 Hz, although in reality it will operate above that frequency [15]. The porous absorber behind the diffuser will be glass wool of 35 kg/m^3 and with a minimum thickness of 60 cm, mounted over the rigid wall. Figure 5 shows a cross-section of the slat absorber with diffuser if one sequence.

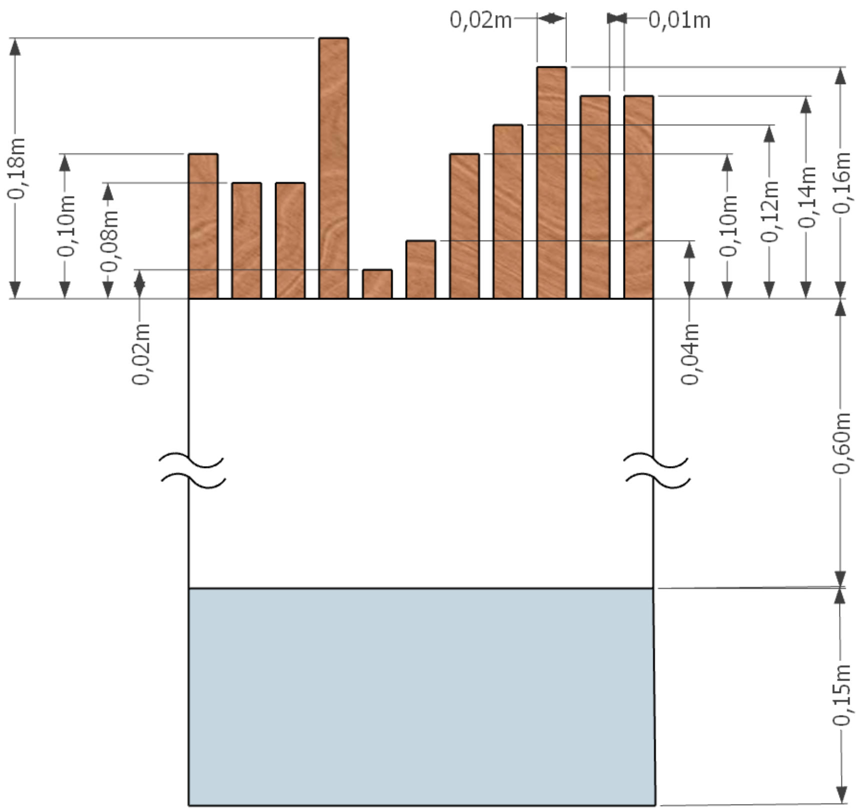

Figure 5. Slat absorber with numerical diffuser of N11, on rigid wall.

4.3 Monitoring system

The proposed monitoring is designed to provide two stereo systems (one near field and one far field), one multichannel system (5 channels plus the sub-woofer) and one binaural system through headphones.

One crucial aspect to improve in the multichannel system is the arrangement of the system. Hiyama, Komiyama and Hamasaki (2002) conducted subjective evaluations of how closely the sound of a reference diffuse sound field, generated by a circular array of 24 loudspeakers, could be approached by arrays of smaller numbers of loudspeakers [16].

Figure 6 shows the different subjective judgments of the degree of impairment in perceived envelopment for various loudspeaker arrangements compared to one circular arrangement of 24 loudspeakers.

It can be seen that the best arrangements (closest to the circular array) are the (b),(c),(d) and (i). This last case is the recommendation by the ITU standard for the 5.1 sound system.

Muraoka and Nakazato (2007) used a measurement of frequency-dependent interaural cross-correlation (FIACC) as a measure of the sound field recomposition. The squared error metric describes the degree of difference between the FIACC at the original location and that reproduced by the test arrangement of loudspeakers [17].

Figure 7 shows comparisons of FIACC measurements in 4 large halls (A,B,C and D).

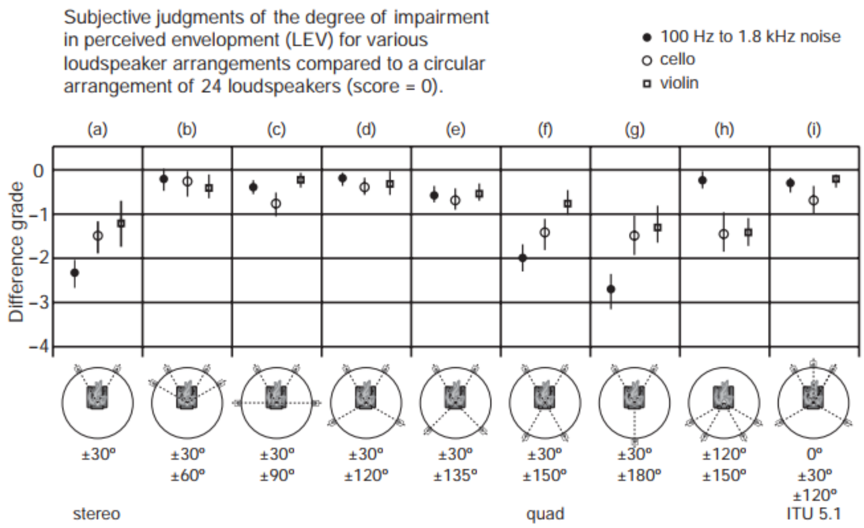

Figure 6. Subjective judgment of degree of impairment in perceived envelopment.

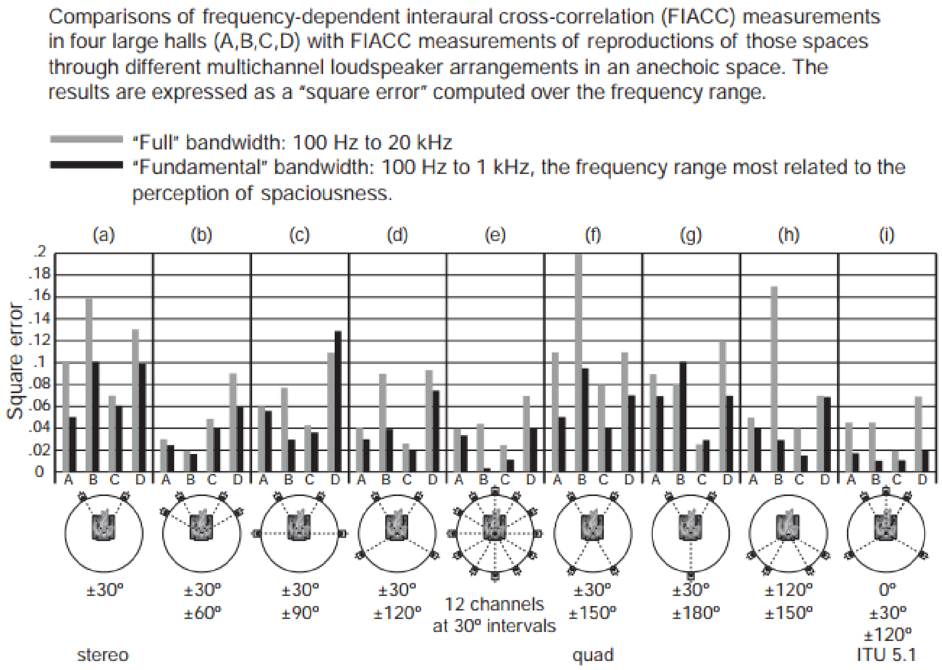

Figure 7. FIACC comparison.

Once again, the best arrangements are the (b), (c), (d) and (i).

The results in the last two figures reveal that the ITU standard is a good option with good results.

The speakers used for the stereo and multichannel systems are the ATC SCM50SL. A three-way active design in which each drive unit in the active model has its own dedicated and individually matched MOS-FET amplifier, while the 234mm/9″ bass driver incorporates ATC's Super Linear Magnet technology. The active crossover network consists of a wide bandwidth, electronically balanced input stage with high common mode rejection and very low distortion [18]. Table 1 shows the technical specifications for the ATC SCM50SL.

In order to guarantee the quality of the monitoring system, the results presented in Table 2 are used. These are supplied by the journal HIFICRITIC [19].

Table 1. ATC SCM50SL technical specifications.

Amplitude Linearity [+- 2dB]	70 Hz - 20 kHz
Frequency Response [-6 dB]	38 Hz - 25 kHz
Max SPL @1m	112 dB SPL
Crossover Frequency	380 Hz ; 3.5 kHz
Input impedance	>10 kΩ balanced XLR
Power	Nominal 90 W, Driven 350 W.
Dimensions (Cabinet)	717 x 304 x 480 mm
Weight	48.9 kg

Table 2. ATC SCM50SL measurement results.

Sensitivity for 2.83 V	85.5 dB @1m
Amplifier loading	Min: 5.5 ohm
Frequency response axial	60 Hz - 25 kHz ±2.0 dB
Bass extension	36 Hz -6 dB; 31 Hz -6dB In-room
Max loudness, in-room	110 dBA - stereo pair.
Power rating	75 W (min), 1000 W (max)
Placement	Stand-mounted, free space 0.3-0.8 m from wall

It is interesting to see the difference between the level and shape of the frequency response off-axis. The ATC SCM50SL datasheet recommends a maximum deviation of 5° below the midrange twitter, the figure above clearly shows the reason, above the axial reference (yellow plot) appears a cancelation in 4 kHz.
For near field monitoring the option chosen is the 8341A by Genelec. A compact three-way monitor with an unusual design because the woofers are hidden behind the front waveguide for the coaxial driver. Table 3 reveals the technical specifications.

Table 3. Genelec 8341A technical specifications.

Amplitude Linearity [+- 1.5dB]	45 Hz - 20 kHz
Frequency Response [-6 dB]	38 Hz - 37 kHz
Max peak SPL @1m	>118 dB SPL
Crossover Frequency	500Hz ; 3 kHz
Harmonic Distortion	<2% [50:100] Hz
Input impedance	10 kΩ balanced XLR
Power	Idle <16 W, Full output 250W.
Dimensions (Cabinet)	315 x 237 x 243 mm
Weight	9.8 kg

The portal Audio science review made a set of measurements using the Klippel Near-Field Scanner (NFS) to the Genelec 8431A which is an excellent database to ensure the quality of the near field monitoring [20]. The results from these measurements are in Appendix A.
The frequency response is flat in all the range (see red line) with variations +1.8/-2.2 dB which is close to the specified by Genelec. Directivity Index which is a measure of how close the direct sound coming from the speaker (pointed at you) differs from sound that is sent to strongest reflections shows very good uniformity, which means that the room would not be very sensitive to the room.
The contour plot shows a smooth decay and controlled horizontal directivity and consequently the listening in different spots will be equally or very similar.

To give the control room a full multichannel system is necessary the implementation of a subwoofer. The ATC SCM 0.1/12SL Pro achieves the expectations as can be viewed in Table 4 with the specifications.

Table 4. ATC SCM0.1/12SL technical specifications.

Cutoff Frequency [- 3dB]	18Hz , 250 kHz
Max SPL @1m	112 dB SPL
Crossover Frequency	380 Hz ; 3.5 kHz
Contour Eq.	6 dB lift @40-60 Hz
Input impedance	>10 kΩ
Dynamic output	1000 W peak.
Dimensions (Cabinet)	581 x 530 x 530 mm
Weight	49.75 kg

In the case of the binaural system the headphones chosen are the EL-8 by Audeze. These models come with planar magnetic drivers which provide an extended frequency response and better dynamics. Furthermore, it comes with a CIPHER cable which transmits high quality digital audio in 24-bit with a DAC with a proper DSP. The technical specifications are given in Table 5 [21].

Table 5. Audeze EL-8 technical specifications.

Frequency response	10 Hz - 50 kHz
THD	<0.1% @1dB
Max SPL	>130 dB
Max Power	3W RMS
Impedance	30 Ω
Sensitivity	98 dB/1mW
Weight	540 g

The results are extracted for the DIY-AUDIO-HEAVEN blog which reviews this particular model and makes measurements to characterize them [22]. The frequency response is remarkably flat. Just a very mild (+3dB) bass boost and a small treble boost, the sub-bass goes below 10 Hz and the two channels are really balanced with each other.

One important aspect to the Binaural hearing is the distortion in the headphones especially at low frequencies. The EL-8 distortion is impressively low and less than 2% at 45 Hz in the very worst condition. According to the author, the spikes may well have been caused by sounds in the demo room.

4.4 Ventilation

The total effective volume of the room is 201,3 m^3. 15 renewals of volume per hour is established to accomplish with the recommendations for carbon dioxide concentrations less than 800 ppm (Eq. 1), for 8 people. Taking a carbon dioxide emission per person, corresponding to a work activity of medium demand (0,13 m^3/h). This determines an air flow of 3019 m3/h, which exceeds the conditions established by Law N° 6.100. To obtain the necessary flow, the Carrier 53 NQ (72K) [23] equipment is chosen, since in its high operating speeds it meets the requirements.

To avoid noise caused by turbulence, an air injection speed of 2 m/s is determined. Therefore it is necessary to use 10 injection grids of *20 cm x 20 cm*. To achieve air renewal, 10 more extraction grids are used. These are placed in the ceiling of the room, in different areas. The

injection grids are derived from a plenum above de acoustic treatment that serves to decrease the speed of the air coming from the outdoor ventilation unit. Also those of extraction go to another plenum that connects to the air extraction duct. In the Appendix B you can see a construction plan with the layout of the grids, ducts and plenums.
The plenums are filled with low-density glass wool to absorb noise that may spread from the ventilation equipment. The ducts to connect the room with the plenums, and the ducts from the outdoor unit are made of absorbent material to avoid noise propagation to the control.

4.5 Sound isolation

For the isolation analysis, the emission sound levels from the control room to neighboring rooms and the immission levels to the interior of the control room are taken into account.
The maximum level of immission to the control room could be the level generated in the recording room next to the control room. This noise will be disregarded in the isolation of the control, since it must be treated in the emitting room, where a box-in-box type construction is generally used, due to the high pressure levels and is also necessary to isolate vibrations. This is not done in this work, since it does not correspond to the control room. To achieve the AES recommendations, the study is considered to be located in a residential area of CABA.
Although Law N° 1.540 does not consider habitable areas as potentially noisy, for the analysis a noise level of an educational establishment, recreational centers corresponding to 90 dBA in the entire frequency range of analysis is taken as a very possible case.
For the analysis of the noise emission from the control room to the outside, an emission level of 85 dBA is considered, corresponding to the maximum level of a working day. As the worst condition of enclosure adjoining a room, corresponding to a Type VII area for Law N° 1.540, which considers a maximum night immission level of 40 dBA. Although nighttime activities are not expected, it is considered a possible condition to take into account.
Taking as a base structure a 30 cm brick dividing-wall, a dry construction is made into the control room of a 50 mm air chamber with steel framing structures on which a double plasterboard is mounted (12,5 + 12,5). On this the acoustic treatment will be mounted. The same will be applied on the ceiling. The studio is considered placed on the ground floor, and the isolation is not carried out. The Transmission Loss calculation of the wall is done in Soundflow software. Figure 8 shows a cross-section of the wall in Soundflow, considering an average value of all cells and air gaps of the diffusers of 2 cm of wood.

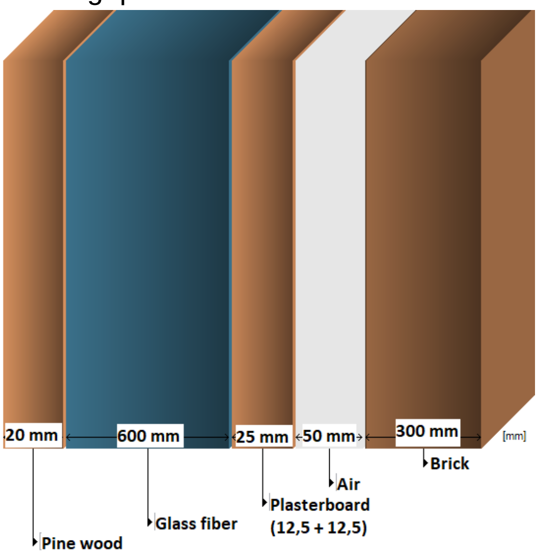

Figure 8. Cross-section of the wall.

5. Results and discussion

This section presents the results of the response of the designed control room. To represent the behavior of the room, an eigenfrequency analysis is carried out by FEM (Finite Element Method) in COMSOL Multiphysics software [24], and a ray-tracing simulation in EASE Software [25] to obtain the reverberation time.

The acoustic treatment of the absorbers and diffusers is analyzed in Soundflow software [26] and Reflex software [27] respectively, although independently due to lack of resources of the full version of the softwares. Figure 9 shows the absorption coefficient of 60 cm of glass wool with 35 kg/m^3 of density. Figure 10 shows the scattering and normalized diffusion coefficient of three sequences of diffusers side by side with gap distance between cells (1 m total), without modulation technique.

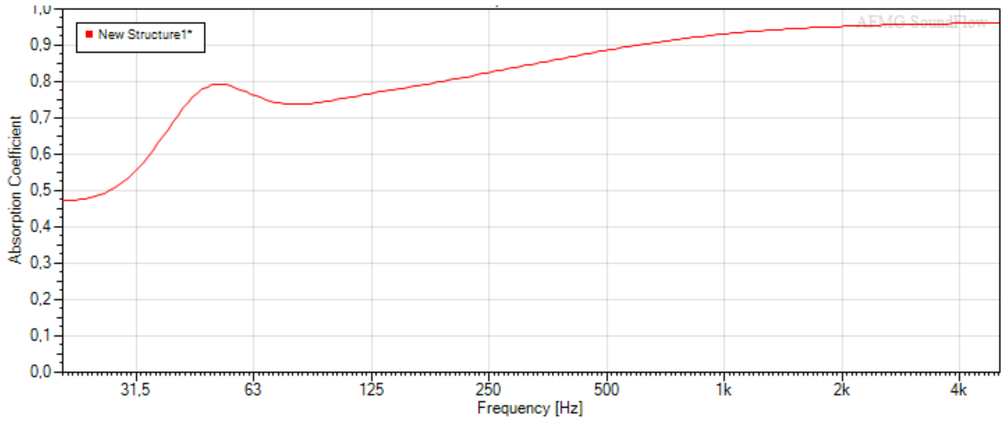

Figure 9. Absorption coefficient of glass wool (60 cm, 35 kg/m^3).

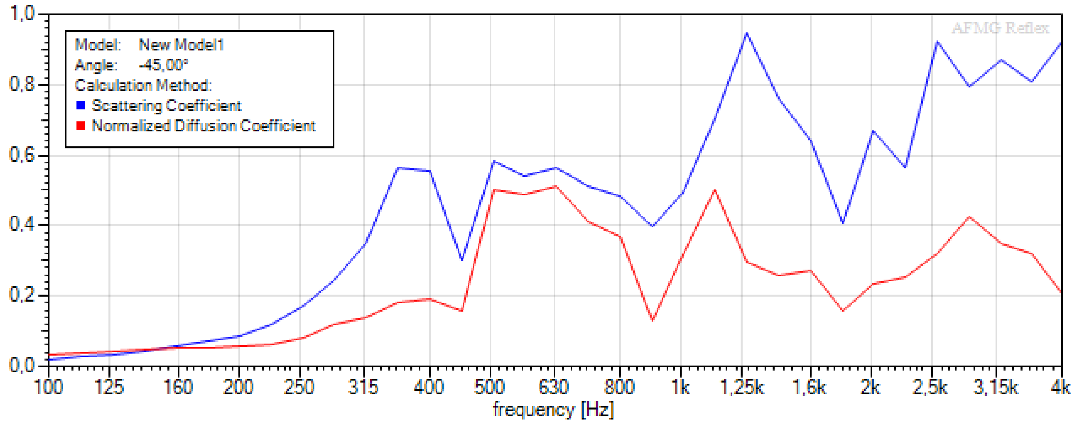

Figure 10. Scattering and normalized diffusion coefficient of three sequences side by side of diffuser with air gap.

Although it could not be simulated entirely, the absorption coefficient is expected to decline in the mid-frequency range, due to being a model of slat absorbers [14]. The coefficient obtained by 60 cm is in accordance with the principles established in ambechoic designs, and the chosen dimensions are achievable in construction.

The diffusion results are also consistent, the simulation results could be better and more representative of reality by expanding the number of sequences used. This was not possible due to the consumption of the computation.

The total volume of the room is 201,3 m^3, according to AES recommendations [12], this room is a small room, the reverberation time should be 0,2 s with a ± 5 % in frequencies greater than 200 Hz, and ± 25 % in frequencies less than 200 Hz. The Schroeder frequency resulting

is 70,5 Hz, taking the higher reverberation time expected. Below this frequency the modal study will be performed.
For the modal study, a simplified geometry of the control room is used, determined by the surface of porous absorbers, since it is assumed that for the frequencies lower than the Schroeder frequency, the diffusers are invisible to the propagation of waves. To represent the absorption, the Delany-Bazley-Miki impedance model is used as a boundary condition [28], with a fine mesh weft. The sound pressure level of each frequency is found in Appendix C, classified according to resonance order. The most marked nodes are in the front-to-back direction. Although the non-parallelepiped geometry contributes to not concentrating the nodal lines in the same direction, the aspect ratios adopted for the symmetry of multichannel audio system are nor entirely optimal. Because some modes have the same or similar frequency as shown in Figure 16.

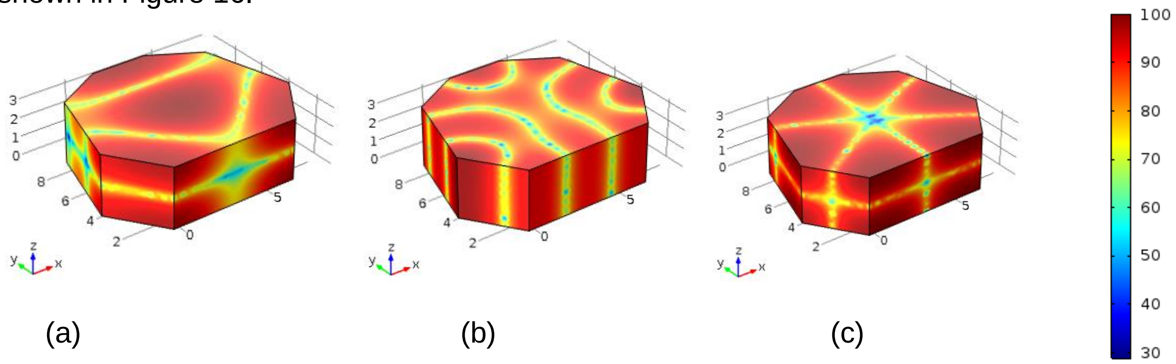

Figure 11. (a) Tangential mode in 67 Hz (y, z). (b) Tangential mode in 68 Hz (x, y). (c) Oblique mode in 69 Hz.

Due to the absorption coefficients obtained from 60 cm of glass wool, it is expected that the attenuation of the model will be greater than that obtained in the free study carried out. It is possible that the absorber impedance model used is not representing the real behavior in natural frequencies, since it solves mainly from the geometry.
Regarding the reverberation time calculation, the software EASE was used to simulate the control room and obtain the results. Due to the limitations of this software the shape of the diffusors on the walls had to be simplified, otherwise the software was unable to recognize the room as a unit. As for the wall materials, a new material was created considering the results obtained previously for absorption and scattering coefficients, and it was assigned to all the walls and to the ceiling. Due to the impossibility of the software to load any information about the diffusion coefficient this was left out. In order to try to implement the diffusion impact on the room, the absorption coefficient curve for the new wall material was modified, lowering the coefficient values as the frequency increases.
The reverberation time values are shown in Figure 12. These parameters were calculated for each one of the 5 main speakers in the room, with the microphone placed in the mixing engineer spot. Figure 12 also shows the AES maximum and minimum recommended RT values for the whole frequency range. The results obtained for the reverberation time are within the limits recommended by AES. Figure 13 presents the values for the early decay time of the control room.

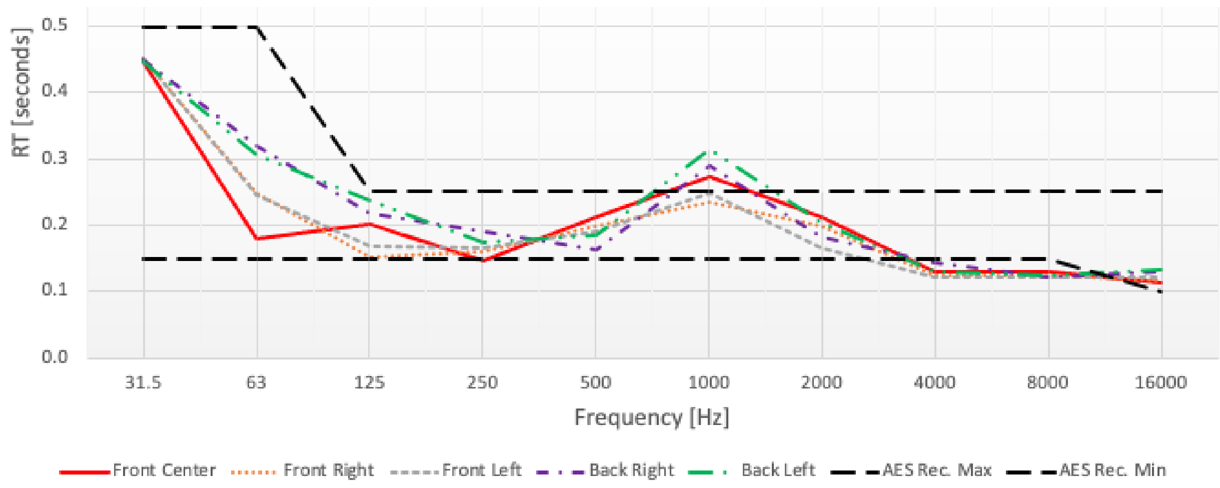

Figure 12. Reverberation time for the designed control room.

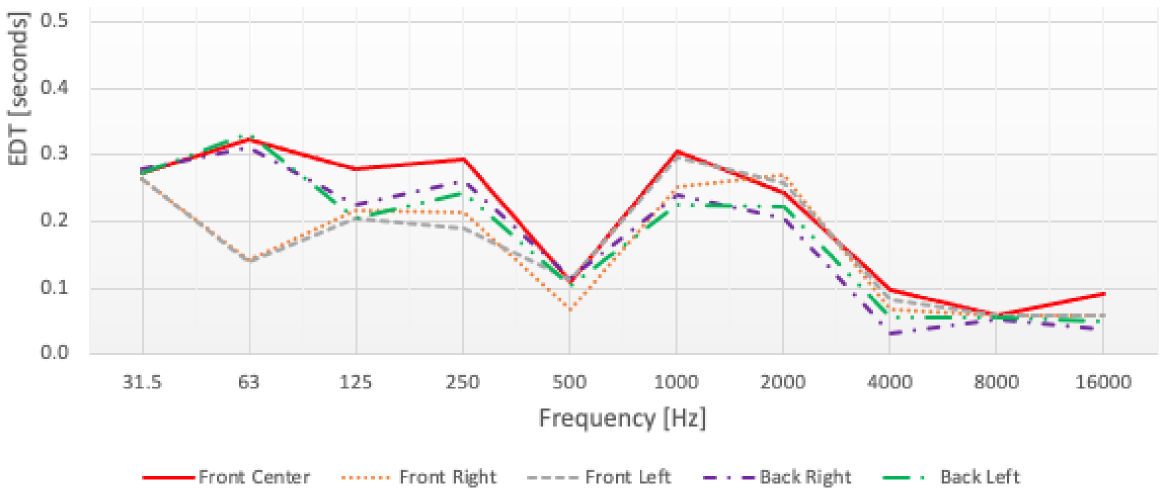

Figure 13. Early decay time for the designed control room.

The transmission loss of the walls and ceiling, and the transcendent levels of immission to the control room and from the control room to the exterior are shown in Table 6 and 7 respectively per octave bands.

Table 6. Emission level, TL, and transcendent level from the control room.

	Frequency [Hz]							
	31,5	62,5	125	250	500	1000	2000	4000
Emission level control room [dBA]	85	85	85	85	85	85	85	85
TL [dB]	44,2	53,3	82,8	132,7	179,7	225,7	233,9	233,9
Transcendent level [dBA]	40,8	31,7	2,2	-47,7	-94,7	-140,7	-148,9	-148,9
Type VII max. level (Law 1540) [dBA]	40	40	40	40	40	40	40	40

Table 7. Emission level, TL, and transcendent level from the exterior to the control room.

	Frequency [Hz]							
	31,5	62,5	125	250	500	1000	2000	4000
Exterior level [dBA]	90	90	90	90	90	90	90	90
TL [dB]	44,2	53,3	82,8	132,7	179,7	225,7	233,9	233,9

Transcendent level [dBA]	45,8	41,7	12,2	-37,7	-84,7	-130,7	-138,9	-138,9
NR10 (AES recommendation) [dBA]	22,6	16,8	14,9	12,4	11,8	10	-	-

By the results of Table 6, it can be seen that the insulation towards the exterior is fulfilled to comply with the levels established by Law N° 1.540. However, the strict recommendations of AES about the NR10 curve for background noise is not fulfilled in the two inferior octave bands (31,5 and 62,5 Hz).

To improve this behavior, it is recommended that the control room be placed in the center of the field where the recording studio is located, and that it has corridors to the recording room, or areas with low noise levels around it. That it is not attached to the engine room, or rooms with little noise control.

Finally, a 3D render of the control room interior design is presented in Figure 14, including the monitoring systems and acoustic treatment. For better quality images please refer to the Appendix D.

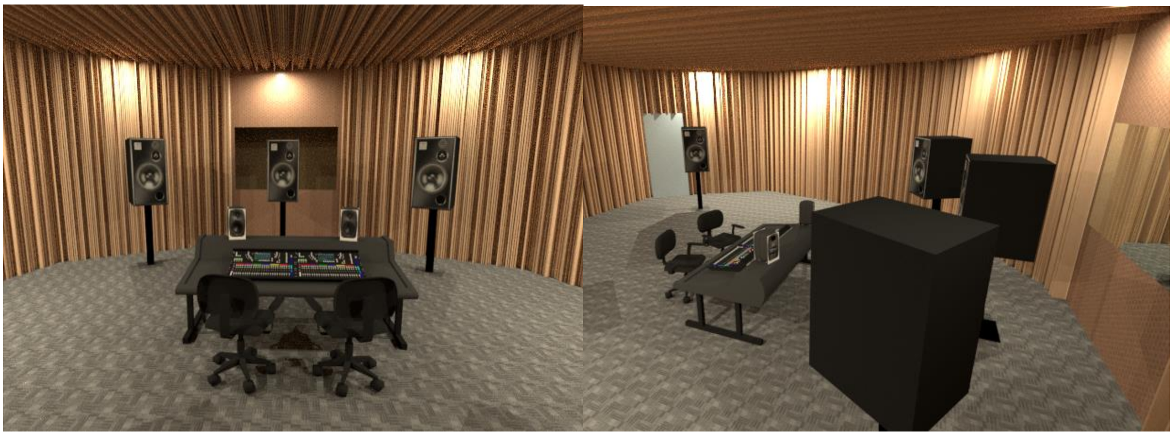

Figure 14. Rendering of the ambechoic control room.

6. Conclusions

The results obtained from the ambechoic control room design are consistent with what is expected in terms of reverberation time, multichannel audio system, absorption and diffusion coefficients, and sound isolation, despite the limitations of the material and geometry simulations of the ray-tracing model. It is important to note the similarity between the left and right monitor speakers RT and EDT curves, this indicates that the designed room shows a near perfect acoustic symmetry.

The modal study was carried out from the frequencies of the geometry, and with the equivalent input impedance model of the absorbent materials, and in a future work a forced study could also be carried out with FEM to better evaluate the attenuation due to the influence of the absorbents. In the same way that being able to study with greater precision the absorption and diffusion of the composed of diffusers with slat absorbers.

If a real project of this control room is carried out, it is suggested to carry out a studio with greater attention in the arrangement and interaction between the rooms or spaces adjacent to the control room, and a strategic arrangement of them in the available space. It is also important to carry out a measurement of the different monitoring systems inside the finished control room and perform the final adjustments needed to provide the best listening experience possible. Although simulation is useful this step should not be overlooked.

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Appendix A

Below, monitoring system details of section 4.3 are presented.

ATC SCM50PSL

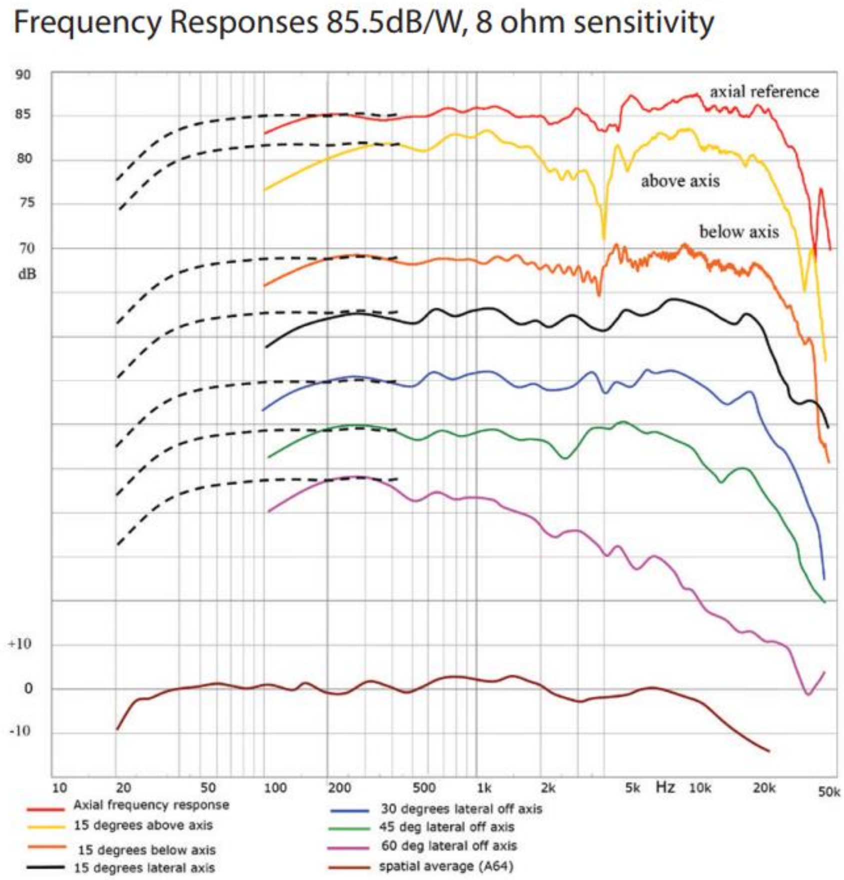


Figure A.1. ATC SCM50SL frequency response graph.

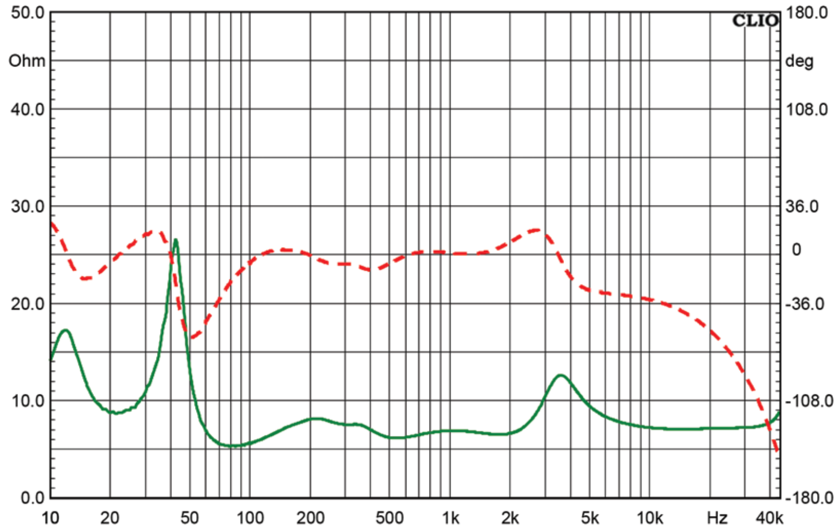


Figure A.2. ATC SCM50SL impedance and phase response graph.

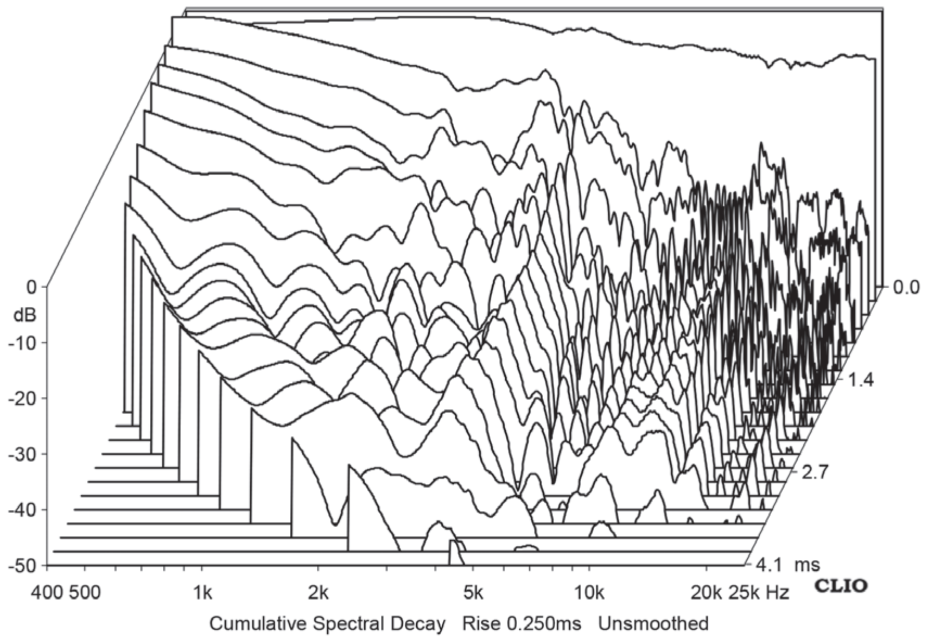


Figure A.3. ATC SCM50SL waterfall plot.

GENELEC 8341A

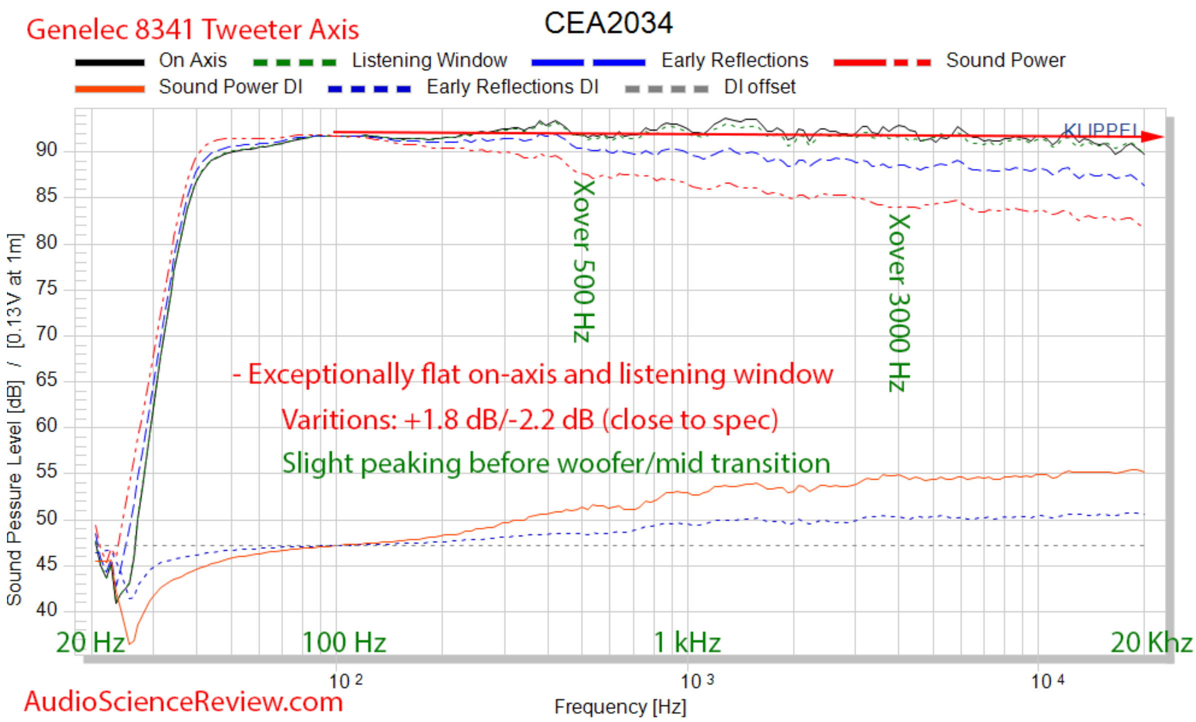


Figure A.4. GENELEC 8341A Spinorama.

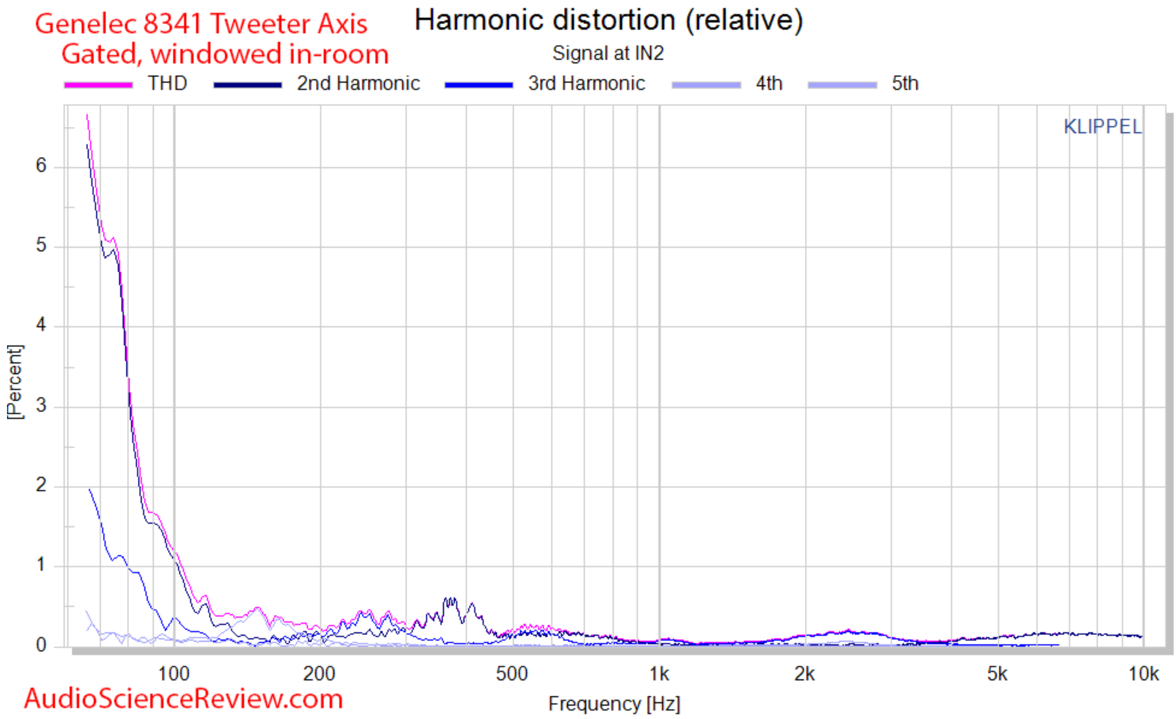


Figure A.5. GENELEC 8341A harmonic distortion response.

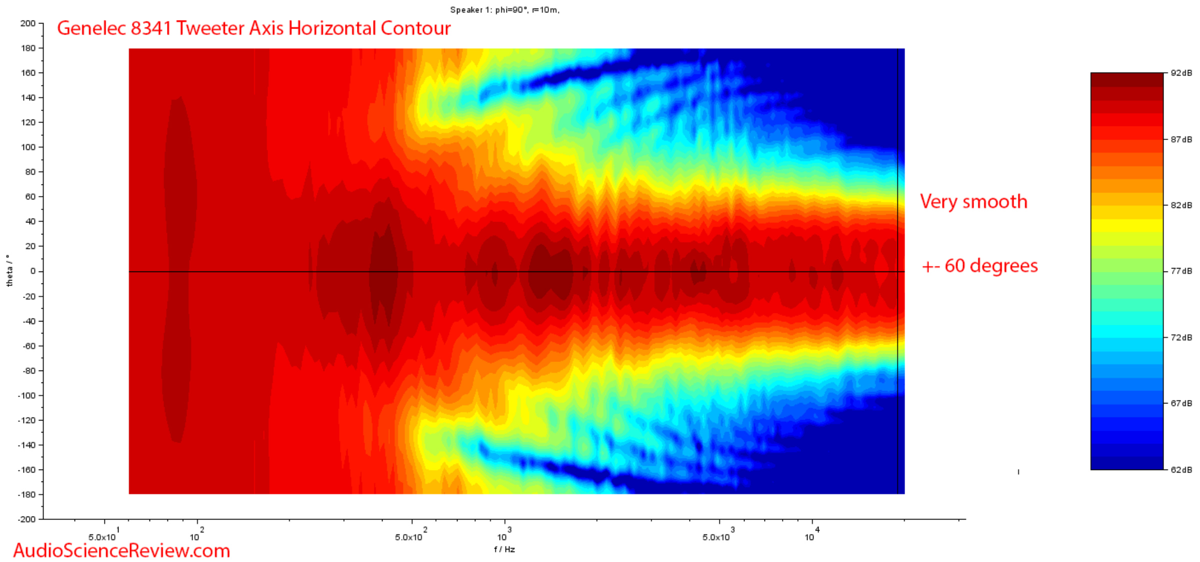


Figure A.6. GENELEC 8341A horizontal contour plot.

AUDEZE EL-8

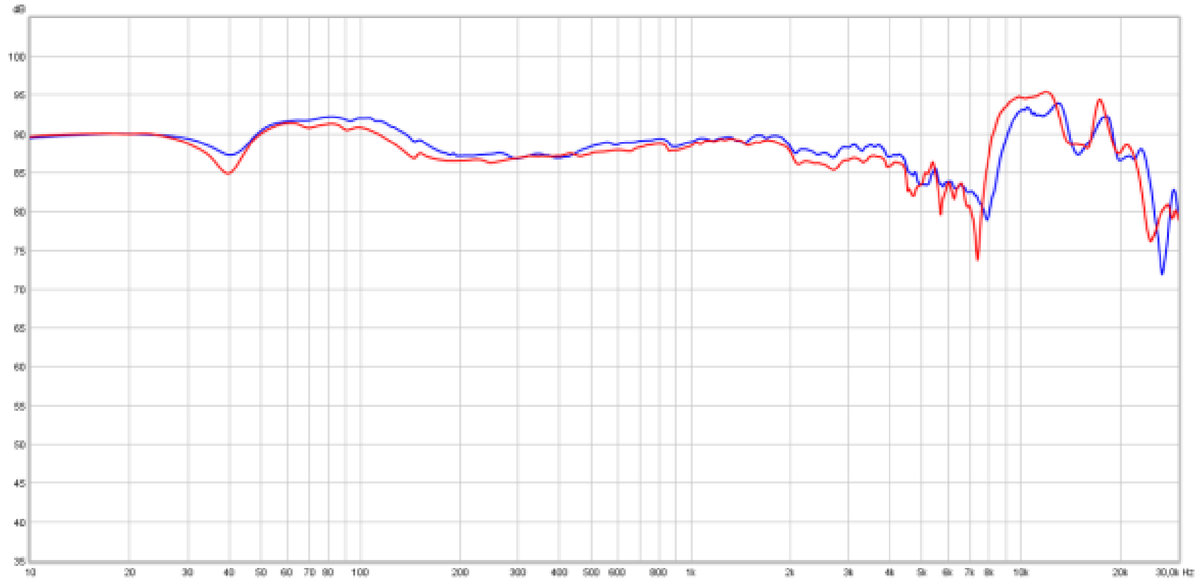


Figure A.7. AUDEZE EL-8 Frequency response graph (L:Blue, R: Red).

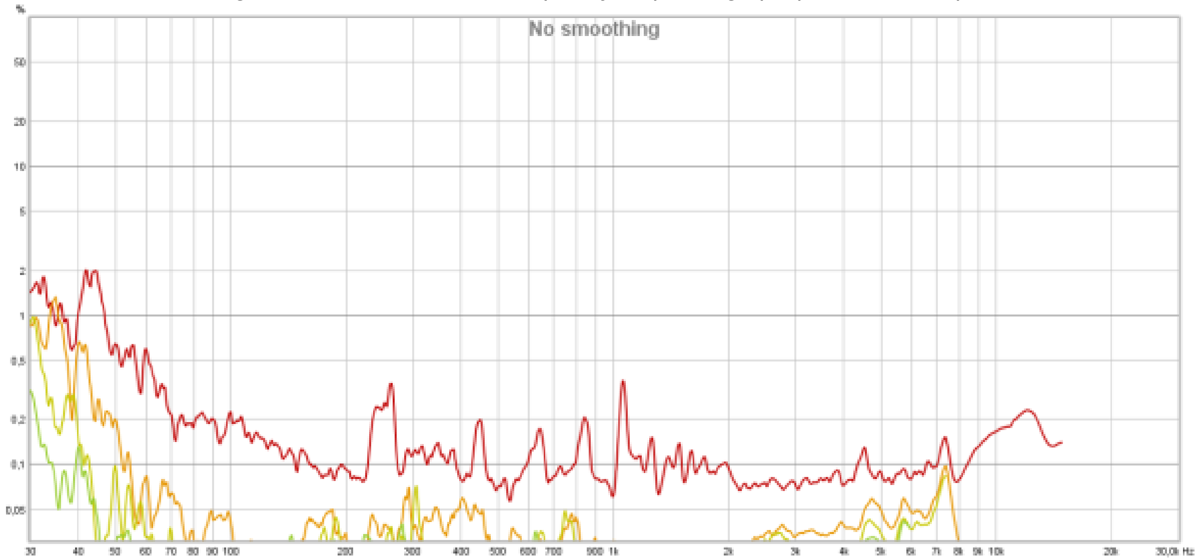


Figure A.8. AUDEZE EL-8 Harmonic distortion response graph..

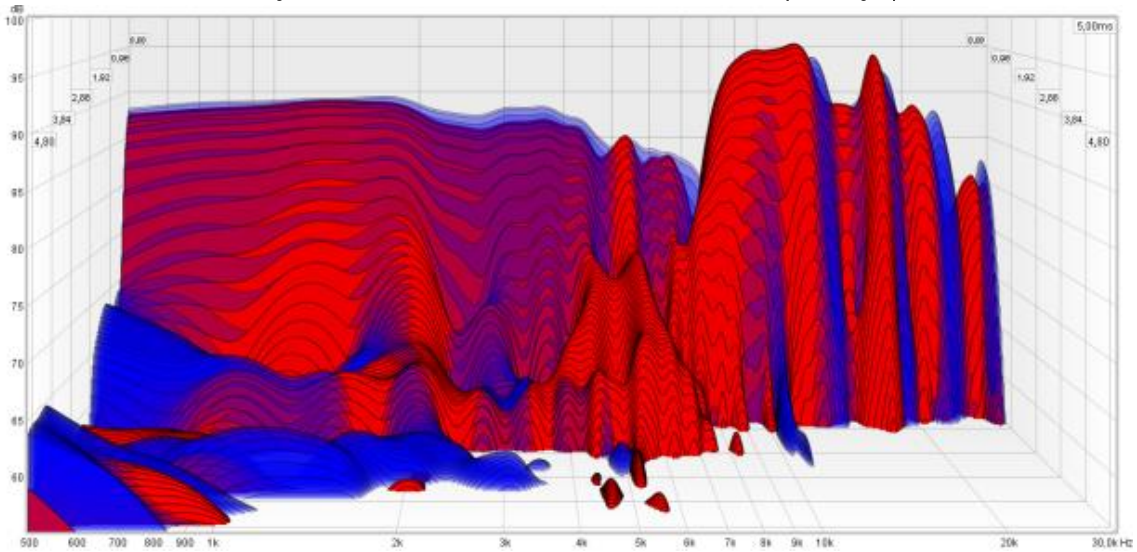


Figure A.9. AUDEZE EL-8 Waterfall plot (L:Blue, R: Red).

Appendix B

The ventilation equipment Carrier 35 NQ [23] is shown in Figure B1. This must be mounted outside the recording studio building, in the correspondent machine room.

Figure B1. Ventilation equipment Carrier 53 NQ.

The plenums of injection and extraction air are filled with low-density glass wool. This can be *Fieltro Liviano* with a thickness of 150 mm provided by Isover (Figure B2 (a)) [29]. The placement must be on the upper slab so as not obstruct the air circulation, and supported with steel framing type structures as shown in Figure A2 (b).

Figure B2. Filetro Liviano by Isover (a) and placement on the ceiling (b).

Also the ducts are made of glass wool but of high-density designed especially by ventilation duct as shown in Figure B3, and provided by Isover [30]. Figure B4 shows the grids of injection or extraction air of 20 cm x 20 cm. Table B1 shows the approximately amount of each material.

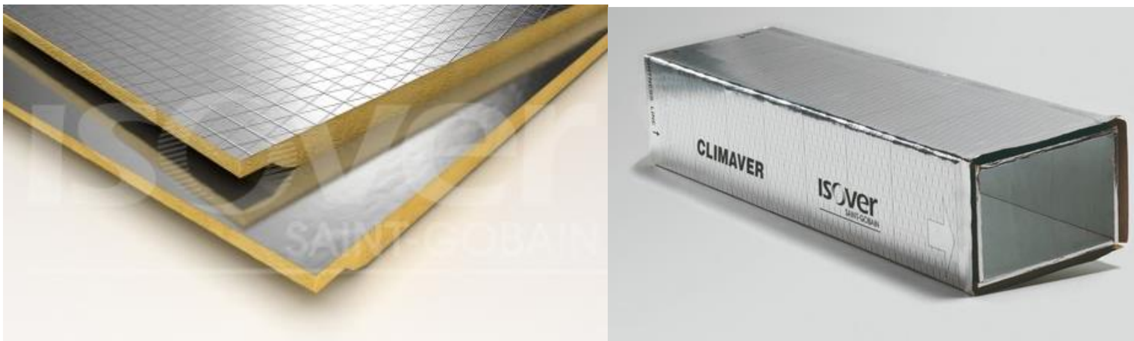


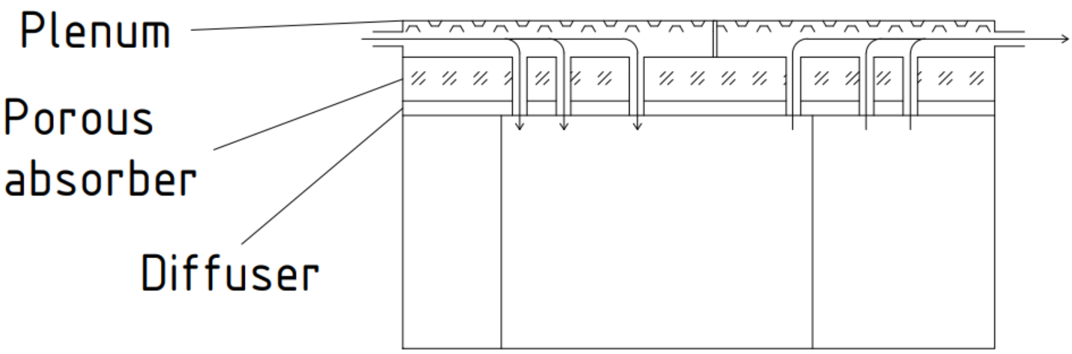
Figura B3. Climaver by Isover as raw material (a), and formed as a duct (b).

Figure B4. Injection or extraction grid.

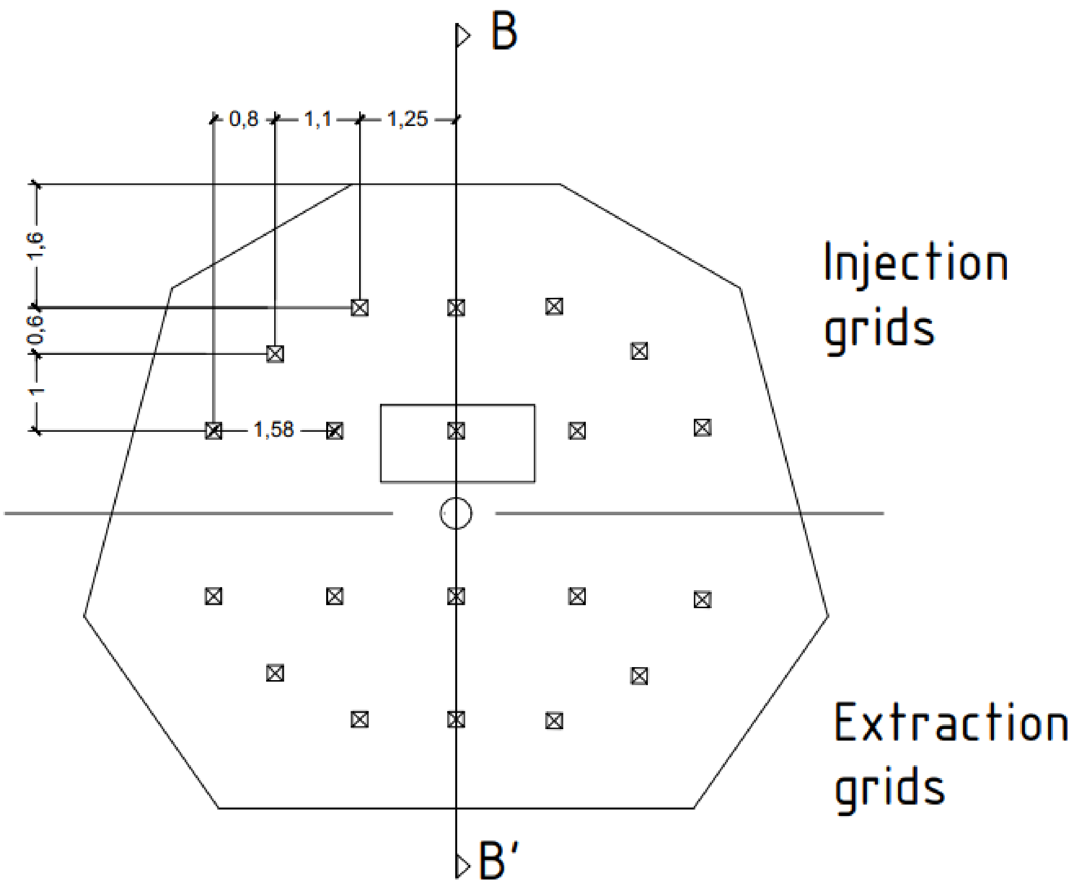
Table B1. Approximately amount of each material

Material	Quantity	Comments
Fieltro Liviano	63 m² approx.	Half for each plenum
Climaver	16 m linear	For ducts to the plenum
	Necessary amount	For duct from the plenum to the outdoor unit.
Grids	20 units	Half for injection, half for extraction

The cross-section of grid, ducts and plenums locations is presented in Figure B5 (a) with its separation dimensions in upper view in Figure B5 (b).



(a)



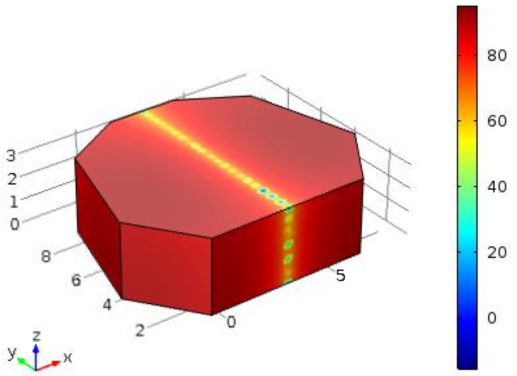
(b)

Figure B5. Injection and extraction grids in the control room without wall details (a), and its ducts to the plenums in cross-section B-B'(b).

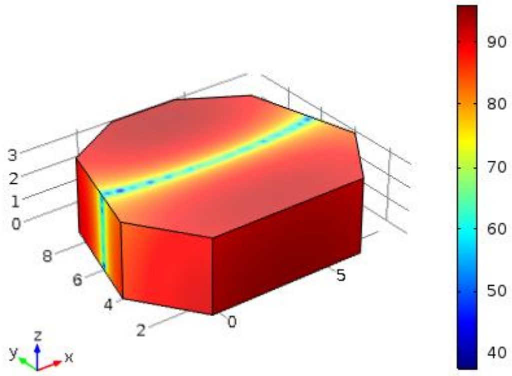
Appendix C

The sound pressure level distribution for eigenfrequencies are shown in this section, below the Schroeder frequency. The first four axial (Figure C1), tangential (Figure C2) and first two oblique modes (Figure C3) are shown. The approximate order is specified according to the ordered axis pair (x, y, z).

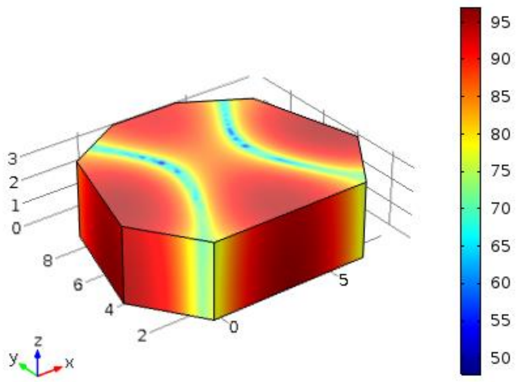
Axial modes



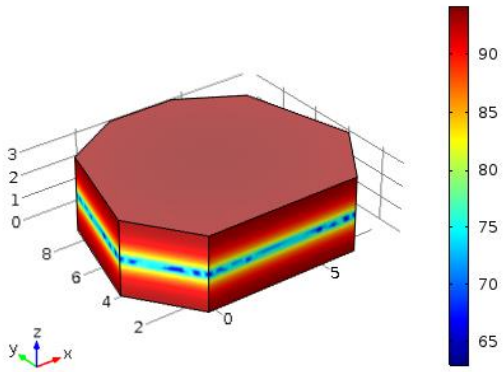
Mode (1,0,0) @29 Hz



Mode (0,1,0) @30 Hz



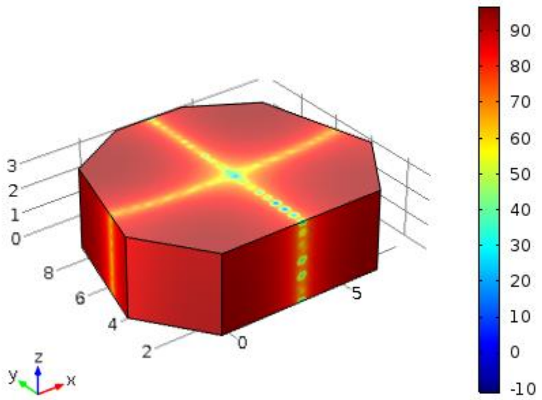
Mode (2,0,0) @40 Hz



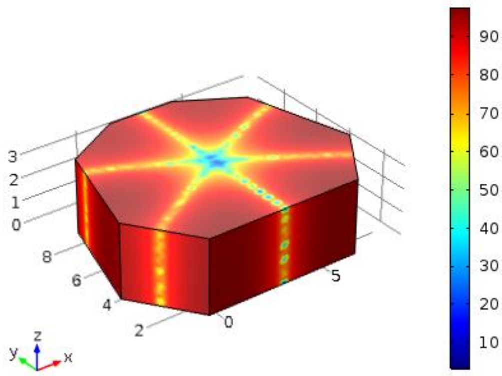
Mode (0,0,1) @54 Hz

Figure C1. First four axial modes.

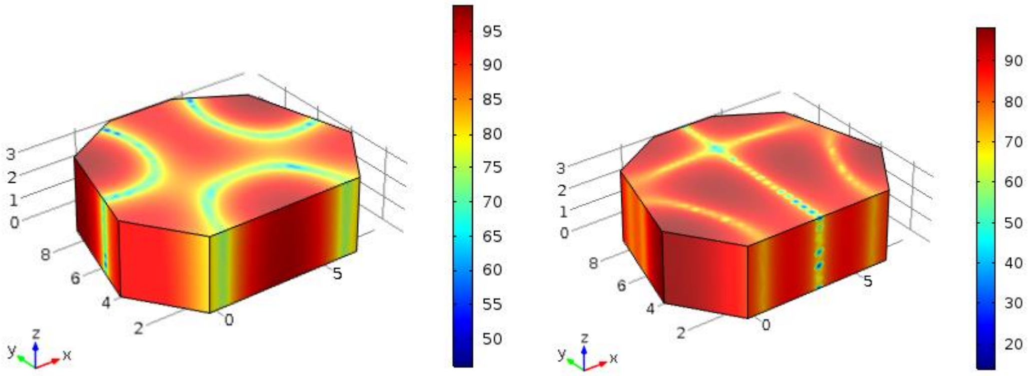
Tangential modes



Mode (1,1,0) @38 Hz



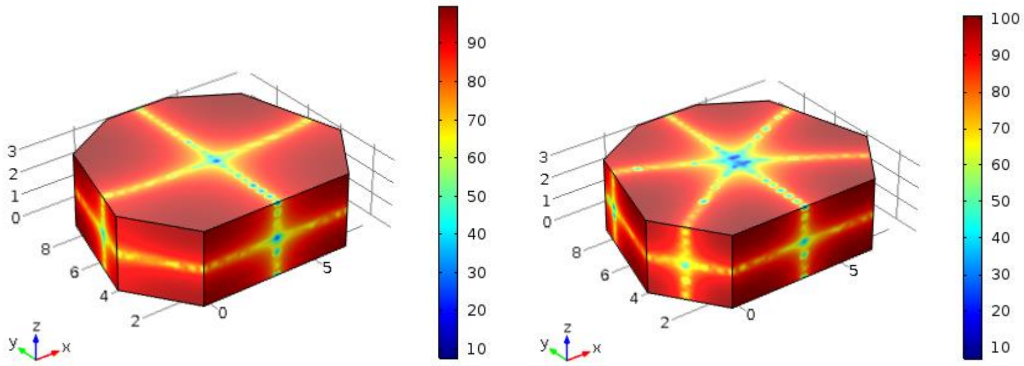
Mode (1,2,0) @48 Hz



Mode (2,1,0) @49 Hz Mode (3,1,0) @56 Hz

Figure C2. First four tangential modes

Oblique modes



Mode (1,1,1) @62 Hz Mode (1,2,1) @69 Hz

Figure C3. First two oblique modes.

Appendix D

Below, the full quality images of the control room's 3D renders are presented.

Figure D1. Control room interior 3D render.

Figure D2. Control room interior 3D render.

Preguntas

- **¿Qué tipos de controles de estudio de grabación hay?**

Se pueden describir diferentes tipos y conceptos de controles para estudios de grabación:

1. **LEDE (Live-End, Dead-End):** los controles hechos bajo este criterio se basan en poseer la mitad frontal altamente absorbente, con una geometría diseñada con el objetivo de producir una zona libre de reflexiones (RFZ) en el sweet spot. La idea se basa en permitir que la primera escucha sea directa desde los monitores y, que luego de un tiempo aceptable (criterio de Haas) las primeras reflexiones lleguen al sweet spot. La mitad trasera de la sala está diseñada para ser altamente difusiva acústicamente, para simular una sensación de ambiente dentro de la sala que no oscurezca la claridad general de la escucha proveniente de los monitores. La mitad frontal de la sala está acústicamente muerta, para evitar que cualquier efecto de la sala regrese de la dirección frontal que podría superponerse espacialmente al sonido directo del monitor. Sin embargo, cabe señalar que algunos de los primeros proponentes del concepto afirmaron que la habitación se define más por las características de su respuesta ETC que por la distribución física de superficies duras y blandas. Estos, estrictamente hablando, no tienen que ir de la mano, aunque muy a menudo lo hacen.
2. **NE (Non-Environment):** en este tipo de controles se busca que la pared frontal y el suelo sean lo más reflectantes posible y todas las demás superficies sean lo más absorbentes posible. Se buscaba que los monitores sean utilizados en una habitación cercana a una anecoica, con los monitores colocados dentro de la pared frontal. Al introducir más absorción en la habitación se reduce la significancia de las reflexiones frente al sonido directo, reduciendo la coloración del sonido. Esto se logra con un costo, dado que este ambiente acústico se aleja totalmente del de una escucha normal.
3. **ESS (Early Sound Scattering):** en este tipo de diseño las reflexiones son tan aleatorias que no tienen carácter que imponer al espacio de escucha. Una sala de control ESS es aquella que cuenta con un extremo frontal altamente difusivo (incluidas las paredes del monitor), que dispersa las primeras reflexiones. El cuerpo de la habitación es absorbente, con la mayoría de las bajas frecuencias amortiguadas por paneles de membrana. Estos diseños buscan un sonido mucho más "vivo" en comparación con las salas de control más antiguas, acústicamente "muertas" o absorbentes.
4. **Ambecoic:** este tipo de diseño busca abandonar la idea del punto de escucha sin reflexiones y trata de adoptar la idea de reducir la coloración del sonido (asociada a reflexiones tempranas). Se realiza un tratamiento acústico basado en lograr mucha absorción en las frecuencias bajas y medias-bajas, y mucha difusión en la zona de frecuencias medias-altas y altas, con una región de cruce entre ambos tratamientos. El volumen final de la sala se ve usualmente reducido por la absorción en bajas frecuencias. Se busca un RT muy parejo para cada una de las fuentes surround y una respuesta en frecuencia para el sistema sorround y el sistema estéreo muy parecida.
5. **Toyoshima Rooms:** en el año 1986, Sam Toyoshima presentó un paper en el diseño de controles para estudios de grabación. En él, se dice explícitamente que el control del estudio debe diseñarse de forma tal que la pared frontal sea reflectante y la pared trasera totalmente absorbente. En caso de no poder cumplirse con la última condición, la pared trasera debe ser diseñada para proveer un alto grado de difusión, aunque, para por ejemplo 85 Hz esto implicaría difusores con componentes de 4 m, lo cual es prácticamente imposible.

- **En caso de no poder resolver un problema modal, ¿cómo se convierte un campo sonoro 3D a un campo sonoro en 2D? (de forma tal de eliminar las ondas estacionarias problemáticas de una de las dimensiones)**

Los modos en recintos o en cualquier otro elemento (como puede ser tubos, placas, membranas, cuerdas o geometrías más complejas) se dan por ondas estacionarias o casi-estacionarias. Esto quiere decir que la onda reflejada (total o parcialmente según sea estacionaria o casi-estacionaria) sobre una superficie se encuentra en fase con la onda que incide sobre ella, creando nodos de mínima presión y anti-nodos de máximos de presión.
Un campo sonoro en 3D implica la propagación de ondas de manera esférica. Dentro de un recinto hay modos en 1D (axiales) que se generan por ondas estacionarias en uno solo de los sentidos de propagación; modos en 2D (tangenciales) generados por reflexiones en dos sentidos; y en 3D (oblicuos) formados a partir de reflexiones en los tres sentidos posibles.
Una onda es estacionaria cuando la reflexión es total (si es casi-estacionaria, la reflexión es casi total), es decir que su coeficiente de reflexión de presión es $R = 1$. Para convertir un campo sonoro de 3D a 2D, se debe buscar anular las reflexiones en un sentido determinado. Esto quiere decir que la reflexión en un sentido no debe existir, y por lo tanto se debe conseguir un $R = 0$, lo cual equivale en cierto sentido a decir que la absorción debe ser total ($\alpha=1$) . Para lograr esto dada una dimensión determinada, debe ser completamente absorbente, o bien ser una superficie suficientemente abierta al exterior de manera de evitar las reflexiones.