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Technical Note

The Reverberation Chamber at the Laboratorio de Acústica y Luminotecnia of the Comisión de Investigaciones Científicas

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ABSTRACT

The reverberation chamber at the Laboratorio de Acústica y Luminotecnia of the Comisión de Investigaciones Científicas de la Pcia. de Buenos Aires is a room of 189 m^3*, of irregular form and with walls on non-parallel planes, used for acoustic absorption measurements. The chamber, its volume computation, the acoustic absorption areas, the reverberation times, the uniformity and diffusion of the sound field and the background noise levels are described.*

The diffusion of the sound field with the addition of different types of diffuser elements randomly suspended from the ceiling was evaluated.

The chamber fulfils the ISO 354 recommendations. Copyright © 1996 Elsevier Science Ltd

Keywords: Reverberation chamber, characterization, diffusion, uniformity.

1 INTRODUCTION

The Laboratorio de Acústica y Luminotecnia contains one anechoic chamber (described in Velis *et al.*[1]), one reverberant room and four rooms for transmission-loss measurements.

All the rooms were designed to perform accurate measurements according to international standards. The reverberant chamber of the acoustic laboratory

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of the Catholic University of Louvain (Belgium), was used as a model for the building of our reverberant room. Both chambers are geometrically identical, but the lining of the walls, ceiling and floor, and the diffuser treatment are different.

The principal use of the chamber is the measurement of the acoustical absorption coefficient of materials and objects in random incidence conditions. To obtain good results it is necessary to fulfil the recommendations specified in ISO 354.[2] It is necessary to verify the conditions in which the Sabine's formula is good enough: low acoustic absorption and good diffusion and uniformity of the sound field.

2 GEOMETRIC CONDITIONS

2.1 Shape

In order to obtain a good uniform sound field, the normal modes of the room in low frequencies must be equally spaced and it is necessary to avoid flutter echo. To obtain this, all the opposite planes, including the walls, ceiling and floor are non-parallel. Figure 1 shows the geometrical development of the room and Fig. 2 shows its shape, corresponding to a seven-surface irregular polyhedron. Two of the four walls are inclined to the interior of the room, with a 82° angle; the other two are vertical. The ceiling of the room has a double slope.

2.2 Volume

The volume of the room is a very important parameter, because it fixes the lower frequency at which it is accurate to measure. On the other hand, the volume must not be unnecessarily large to avoid air absorption at high frequencies. The ISO requirements are for a volume near to 200 m^3 for measurements down to 100 Hz.

Volume is also a parameter in the equation for equivalent sound absorption area, and so it is necessary to know it accurately.

$$A = 55.3\,\frac{V}{c}\left[\frac{1}{T_2} - \frac{1}{T_1}\right]\,[\mathrm{m}^2] \tag{1}$$

where A is the equivalent sound absorption area, V is the volume of the room [m^3], c is the speed of sound [m/s], T_2 is the reverberation time with the sample [s], T_1 is the reverberation time without the sample [s].

The relative error in the equivalent sound absorption area is:

$$e_A = \pm(e_V + e_c + e_{(1/T_2 - 1/T_1)})$$

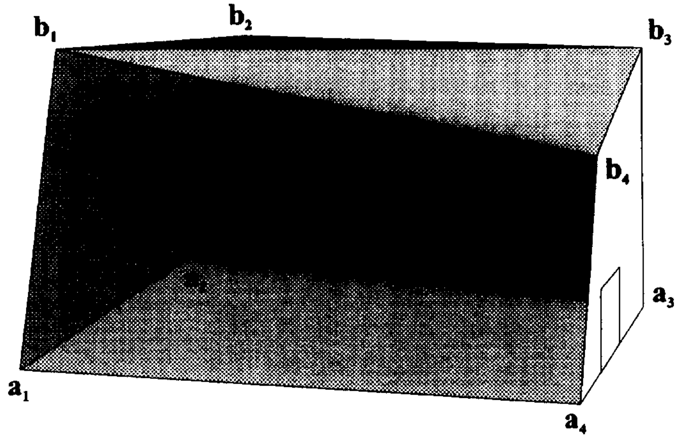

Fig. 1. Geometrical development of the room (dimensions are in m).

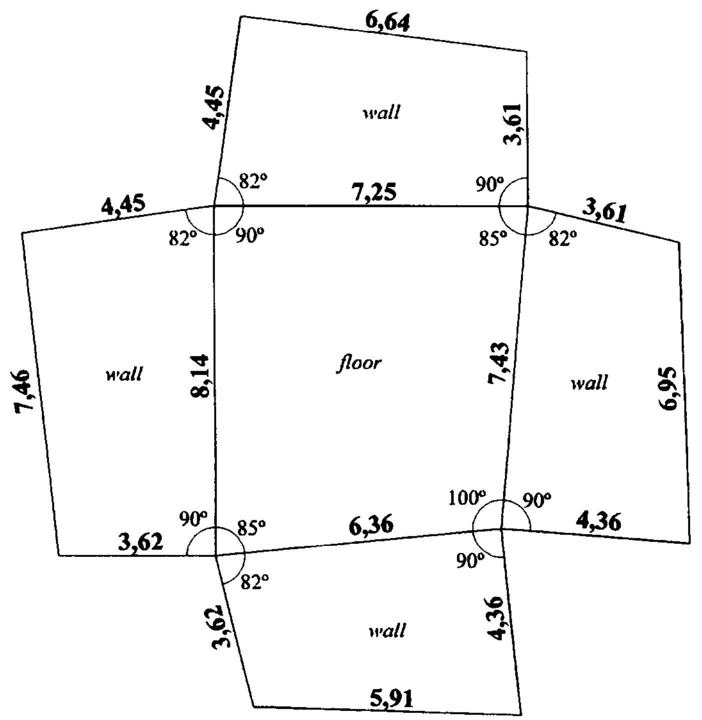

Fig. 2. Shape of the reverberation room.

where e_V is the relative error of the volume, e_c is the relative error of the speed of sound and, $e_{(1/T_2-1/T_1)}$ is the relative error of the difference of the inverse reverberation times.

The computation of a seven-surface irregular polyhedron volume is awkward and the details of this computation are given in the appendix. The volume of the chamber was found to be:

$$V = (189 \pm 2)\,[\mathrm{m}^3]$$

The total surface area of the room is 208 m^2, and the length of the longest straight line which fits within the boundary of the room is 11 m.

3 REVERBERATION TIMES

Reverberation times of the room were measured with an impulsive method, using band-filtered noise burst. This choice was based on the better reported precision that the impulsive method has compared to the interrupted random-noise method recommended in ISO 354.

It is important to note that there are systematic differences in the results obtained when measuring by both methods. Although the deviations are small, the methods are not equivalent. We believe that the impulsive method, using band-filtered noise burst, is the most accurate one (see, for example, Vorländer and Bietz[3]).

The measuring method employed a function generator and an acquisition system, both controlled by a personal computer. The signals used to excite the chamber were sine waves, and the amplitude was modulated with Hamming windows. The frequency of the sine wave corresponds with normalized centre bands and the temporal length of the window was selected in order to achieve an equivalent bandwidth of one-third of an octave.[4]

Six points within the room, at least 1.7 m apart, 1 m from the walls and 1.8 m height, were measured. The sound source was positioned at one of the room corners (see Fig. 3).

The reverberation times were determined with and without diffusers randomly suspended from the ceiling. Three different configurations of diffuser were used, described as:

- five square acrylic plates slightly curved, 8 mm thickness, 1.4 m^2 area, 6.9 $\mathrm{kg/m}^2$ weight per unit area;
- five expanded polystyrene spheres, 30 mm thickness, 0,94 m diameter (2.7 m^2 area and 0.43 m^3 volume), 0.9 $\mathrm{kg/m}^2$ weight per unit area;
- five expanded polystyrene spheres and four acrylic plates.

Since the weight per unit area of the spherical diffusers is less than typical recommendations it is possible that their absorption reduces the reverbera-

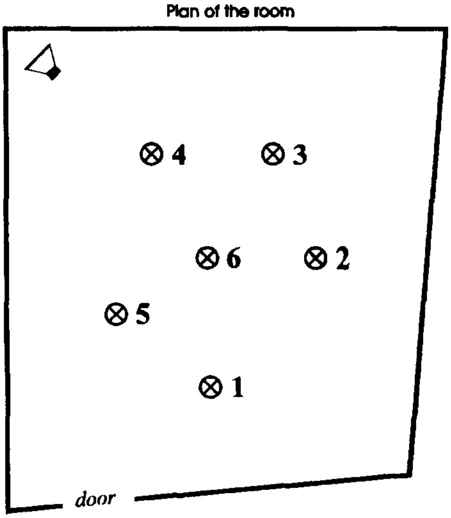

Fig. 3. Locations of measurement points.

tion times of the chamber at some frequencies. In spite of this, the chamber still met ISO recommended absorption values as shown in Fig. 8.

Figure 4 shows the spatial average of the measured reverberation times of the empty chamber, and Figure 5 shows relative deviations (ratio between sample standard deviation and sample mean value). Figures 6 and 7 are similar but with the chamber equipped with a sample of glass-wool (50 kg/m^3 density, 5 cm thickness and 10 m^2 area).

The reverberation times shown are based upon the first 10 dB of the Schroeder's integral fall.

4 ABSORPTION AREAS

In order to obtain a suitable reverberant sound field, equivalent sound absorption areas of the surfaces of the room must be small. For this, the chamber walls and ceiling were painted with epoxy paint and the floor made with polished granite. Figure 8 shows ISO recommended absorption values for the chamber volume, together with the measured values for the room with and without diffusers.

5 UNIFORMITY

Figure 9 shows sound level spatial standard deviations, for each frequency band, measured at the six points. Figure 10 shows the same but with the

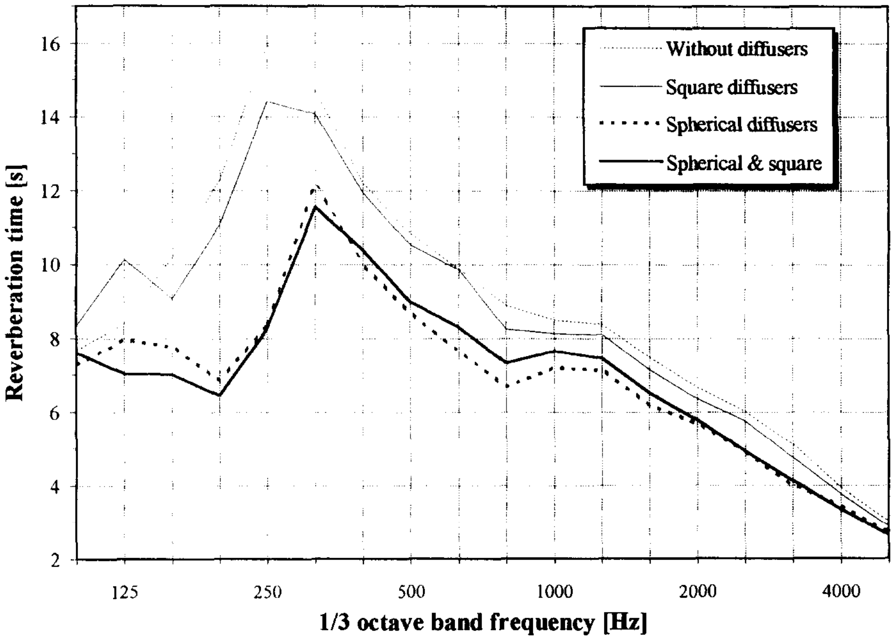

Fig. 4. Spatial average of the measured reverberation times of the empty chamber.

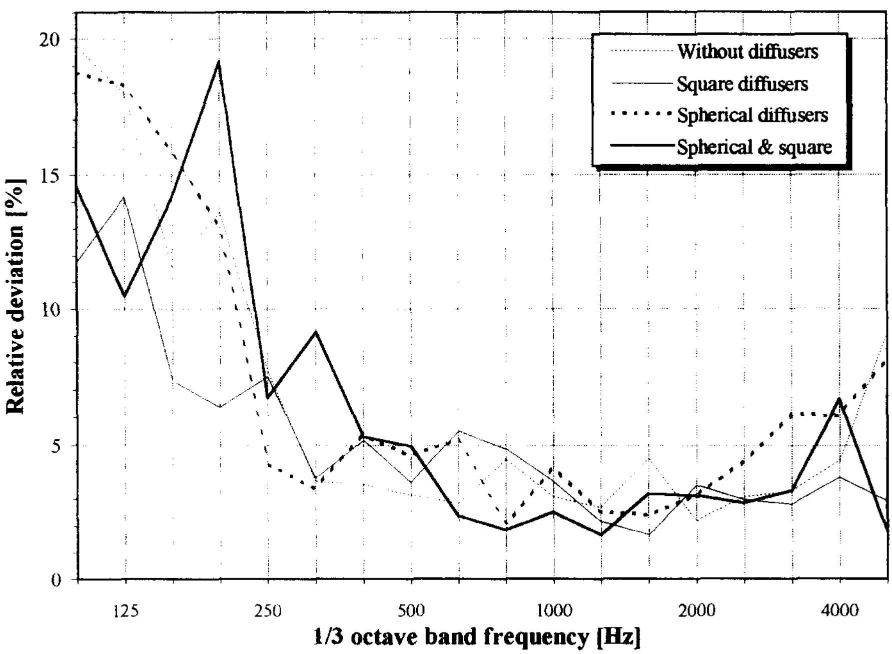

Fig. 5. Relative spatial standard deviations of the reverberation times of the empty chamber.

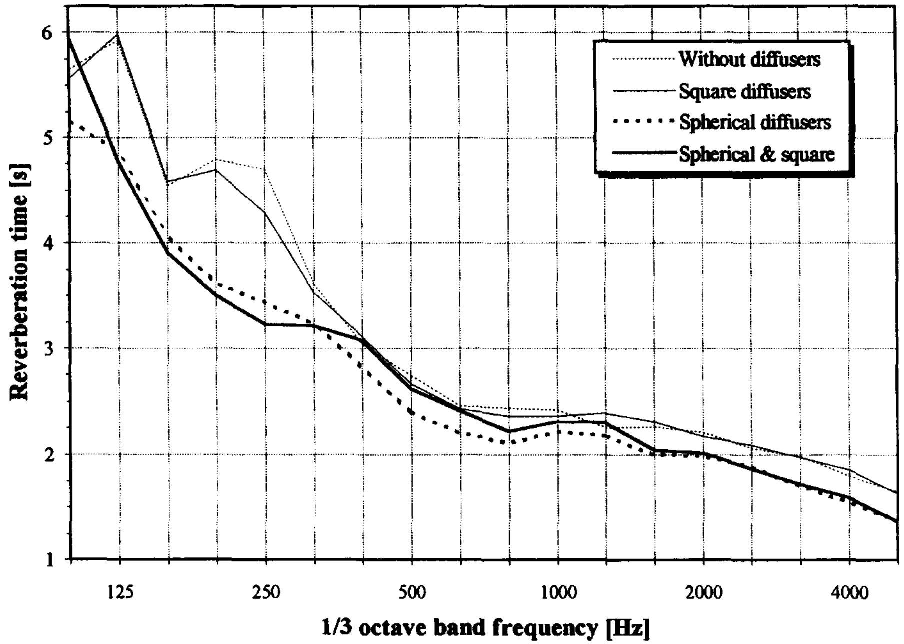

Fig. 6. Spatial average of the measured reverberation times with a chamber equipped with a sample of glass-wool (50 kg/m^3 density, 5 cm thickness and 10 m^2 area).

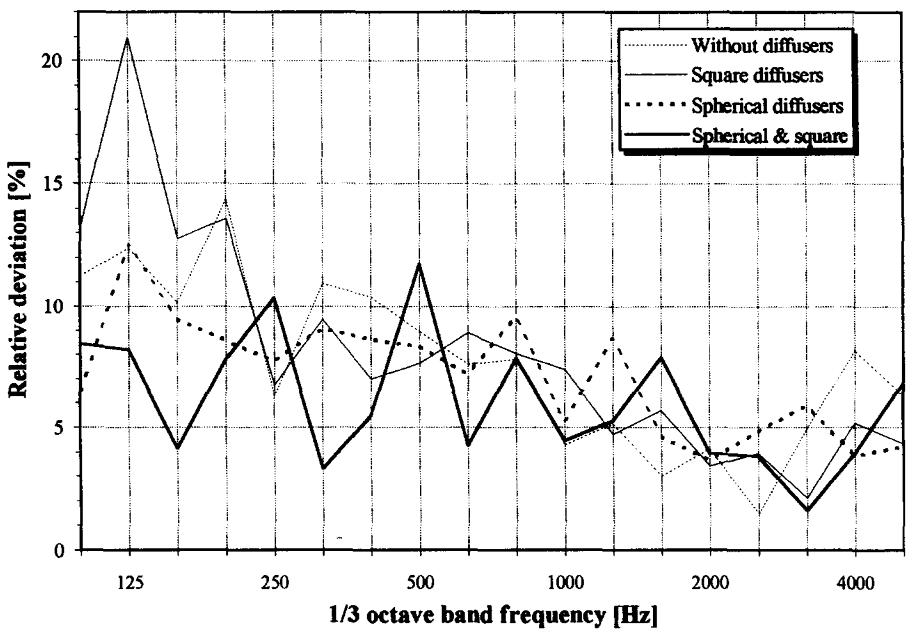

Fig. 7. Relative spatial standard deviations of the reverberation times of the chamber equipped with the sample.

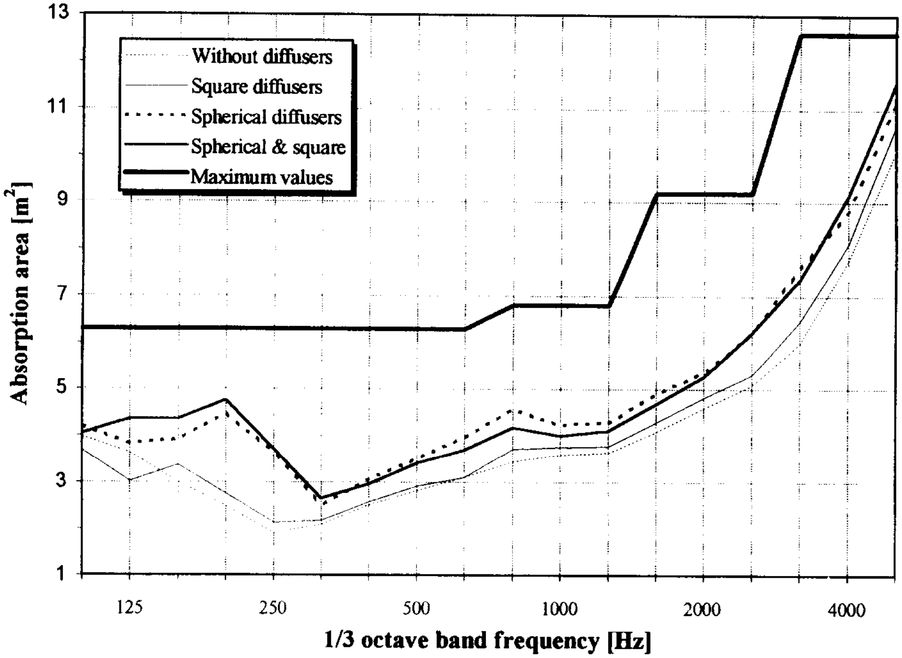

Fig. 8. Absorption areas.

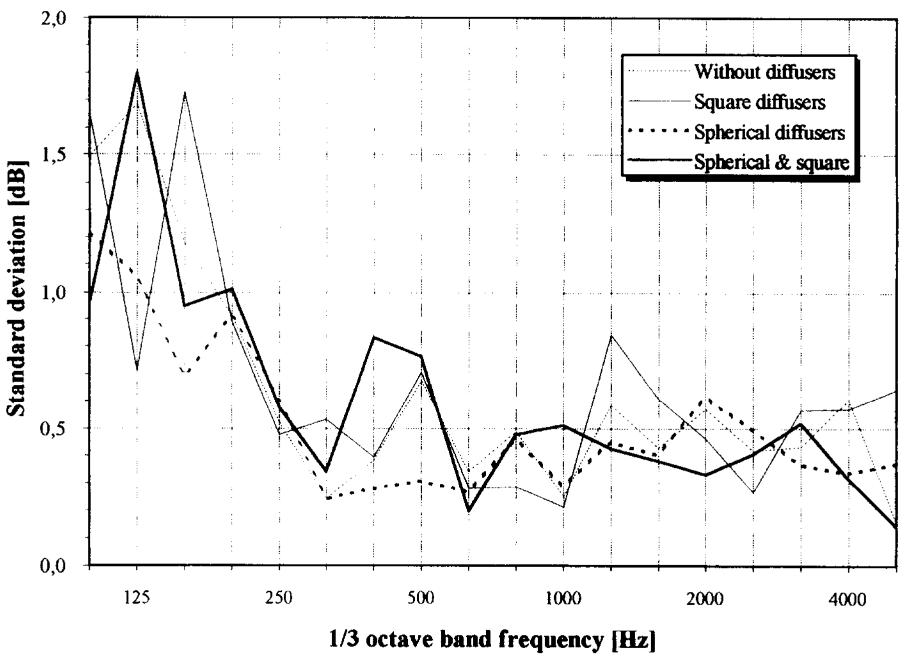

Fig. 9. Sound-level spatial standard deviations of the empty chamber.

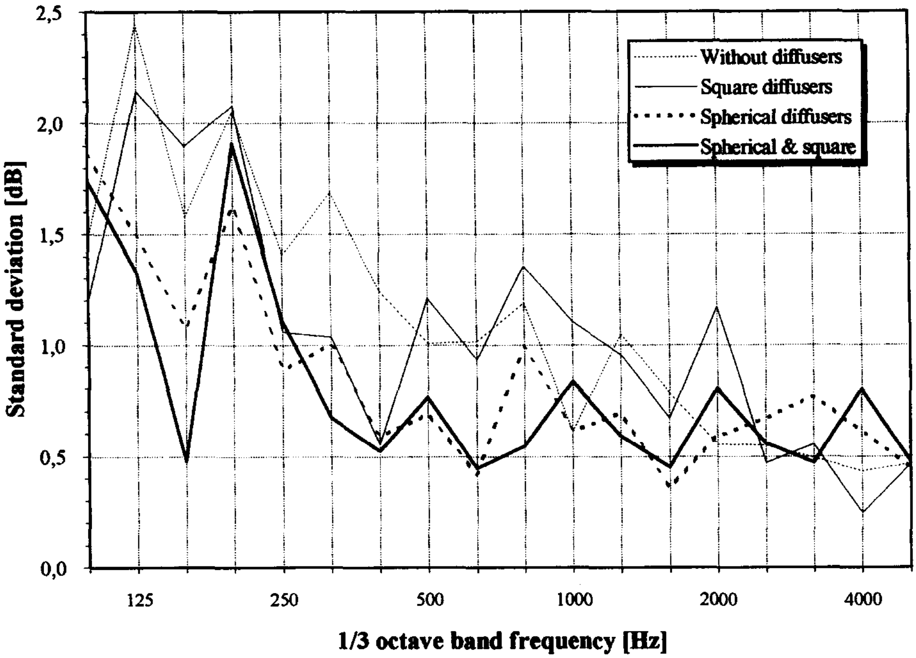

Fig. 10. Sound-level spatial standard deviations of the chamber equipped with the sample.

chamber equipped with the glass-wool sample. The chamber was excited with white noise.

6 DIFFUSION

A very good diffusion within the chamber is essential to fulfil Sabine's formula, in order to perform accurate measurements of the sound absorption coefficient. Different methods may be used to qualify the diffusion[5] but in this work the ISO 354 recommended method was adopted: that is, measure the sound-absorption coefficient of a high-absorption material with increasing number of diffusers randomly distributed inside the chamber. When the measured absorption coefficient reaches a maximum and constant value, the best diffusion condition is obtained. Figure 11 shows the absorption coefficients of a glass-wool sample, 50 kg/m^3 density, 10 m^2 area and 5 cm thickness, measured with and without the three types of diffuser array described in section 3. Values measured for normal incidence in the stationary wave tube are given too. Figure 12 shows the relative spatial standard deviations of the measured absorption coefficients, as calculated only for comparative purposes.

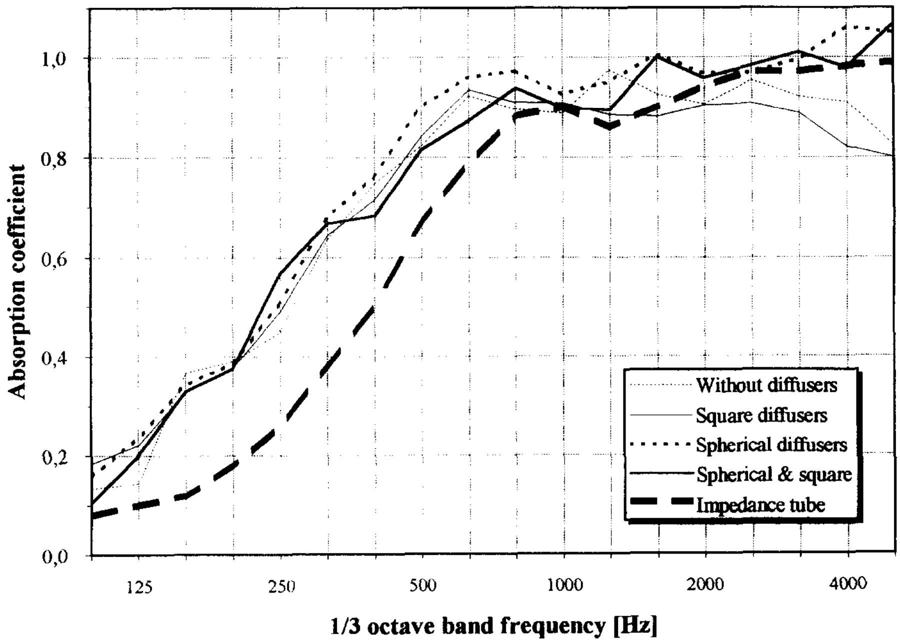

Fig. 11. Absorption coefficients of a glass-wool sample measured with and without three types of diffuser array (50 kg/m^3 density, 5 cm thickness and 10 m^2 area).

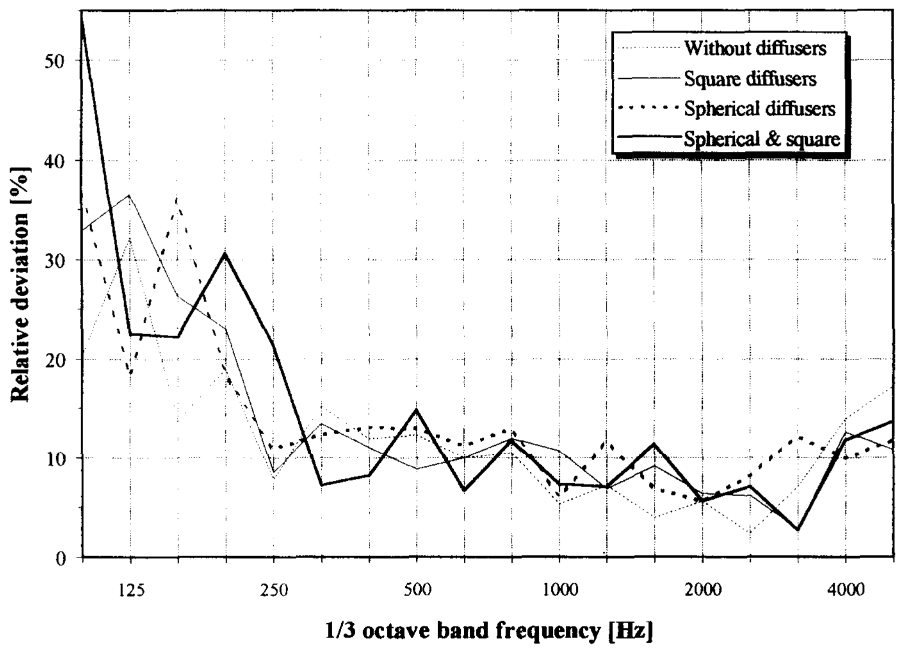

Fig. 12. Relative spatial standard deviations of the measured absorption coefficients.

7 BACKGROUND NOISE

The reverberating chamber requires very good acoustic isolation, in order to isolate noises from the outside, and at the same time, to avoid affecting the other rooms of the laboratory by sounds generated inside the chamber. To achieve this a double structure was built: the interior one using concrete and the exterior using brick. The space between both boxes is filled with glass-wool panels. The inner box is mounted on helicoidal springs, each one supporting a weight of 1 tonne. The resonance frequency of the system is about 3 Hz. The access to the room is through two acoustical doors, one mounted on the external wall and the other on the inner box.

The background noise level inside the chamber for a normal outside noise is 22 dB (A).

8 CONCLUSIONS AND COMMENTS

The reverberating chamber volume allows measurements of 100 Hz third octave and above, according to ISO 354. The absorption areas are under the maximum recommended values. The reverberation time relative spatial standard deviations, at low frequency, seem to be higher than those of other chambers[6] but direct comparisons are not possible because different methods have been employed,[5,7] (impulsive burst versus interrupted random noise).

The sound field is very uniform, so the normal modes distribution is good. Only small variations are present for different diffuser configurations.

A noticeable increase of the absorption coefficient at high frequencies was observed with the use of the spherical diffusers. This increase was similar to the one obtained in the chamber of Benedetto *et al.*[7] but in our case with fewer diffusers. This fact shows that the diffusion of the chamber is already good in the initial slope of the decays curves, even with few diffusers.

The method used to measure the reverberation time allows one to quantify the first 10 dB of the decay curves, as opposed to traditional methods. Therefore, it is enough to accomplish a good diffusion in the first 10 dB of the decay curves.

The absorption coefficient variations, for different diffusion conditions are as stated in Benedetto and Spagnolo.[8]

The background noise level is within the acceptable limits.

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APPENDIX

Computation of the volume of the chamber

To obtain the volume of the chamber, it was divided in six tetrahedrons. The tetrahedrons chosen, expressed by the three vectors that defined them, are shown in Table 1 (see Fig. 2).

Each tetrahedron's volume was calculated as one-sixth of the absolute value of the determinant developed by the coordinates of its vertices.[9] For instance, for tetrahedron 1

$$V_1 = \frac{1}{6} \times \text{abs} \begin{vmatrix} a_{3x} & a_{3y} & a_{3z} & 1 \\ b_{2x} & b_{2y} & b_{2z} & 1 \\ b_{3x} & b_{3y} & b_{3z} & 1 \\ b_{4x} & b_{4y} & b_{4z} & 1 \end{vmatrix} \tag{A1}$$

The column of ones carry the vector to the coordinate origin, in order to obtain a square matrix.

According with the theory of the error propagation, the absolute error of each volume results in the addition of the measurement errors of the coor-

TABLE 1
Determining vectors for the chosen tetrahedrons

1	$\overline{a_3b_2}$	$\overline{a_3b_3}$	$\overline{a_3b_4}$
2	$\overline{b_4a_2}$	$\overline{b_4a_3}$	$\overline{b_4a_4}$
3	$\overline{b_2a_2}$	$\overline{b_2a_3}$	$\overline{b_2b_4}$
4	$\overline{a_1b_1}$	$\overline{a_1b_2}$	$\overline{a_1b_4}$
5	$\overline{b_4a_1}$	$\overline{b_4a_2}$	$\overline{b_4a_4}$
6	$\overline{b_2a_1}$	$\overline{b_2a_2}$	$\overline{b_2b_4}$

dinates multiplied by the value of the minor complemental determinant of this coordinate. For the first tetrahedron

$$E_{V_1} = \pm\left[E_{a_{3x}} \times \text{abs}\begin{vmatrix} b_{2y} & b_{2z} & 1 \\ b_{3y} & b_{3z} & 1 \\ b_{4y} & b_{4z} & 1 \end{vmatrix} + \cdots + E_{b_{4z}} \times \text{abs}\begin{vmatrix} a_{3x} & a_{3y} & 1 \\ b_{2x} & b_{2y} & 1 \\ b_{3x} & b_{3y} & 1 \end{vmatrix}\right] \quad \text{(A2)}$$

where $E_{a_{3x}}$ is the absolute error in measuring a_{3x}, and $E_{b_{4z}}$ is the absolute error in measuring b_{4z}.

Measuring the coordinates with an absolute error of ± 1 cm, the volume is determined with a $\pm 1\%$ relative error.