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The reverberation time and equivalent sound absorption area of rooms in dwellings

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The study gives the results of the measurements of the reverberation time in 11,687 rooms, of which 11,457 are furnished (8,246 bedrooms, 3,211 living rooms), and 230 unfurnished. All the rooms have thick walls and ceilings and a heavy floor covering. The reverberation times measured are quite similar in bedrooms and living rooms within the same size range, and decrease fairly uniformly as the frequency increases. Moreover, in each frequency band the greater the volume of the room, the greater the reverberation time. The results of this extensive fieldwork allow us to predict accurately the reverberation time in these kinds of spaces as a function of their size and the frequency. These data may be useful for improving the accuracy of calculation models to estimate the reverberation time of enclosed spaces. The equivalent sound absorption area of these rooms was also calculated.

1. INTRODUCTION

In the evaluation of airborne sound insulation between rooms [1], impact sound insulation of floors [2], and airborne sound insulation of facades [3], it is necessary to measure the reverberation time of the receiving room. An important objective of architectural acoustics is to predict the reverberation time in enclosed spaces. The possibility of estimating the reverberation time of each frequency band as a function of the volume of the room would represent a time saving when carrying out *in situ* acoustic measurements, without compromising the accuracy of the results.

This paper presents the results of the reverberation times measured in a wide selection of rooms between the years 2000 and 2003 in the Madrid region in Spain. This wide-ranging program of acoustic measurements was commissioned by the official bodies supervising the implementation of new runways in the expansion of the Madrid-Barajas International Airport. The acoustic measurements were carried out in 11,687 rooms in dwellings, of which 8,246 were bedrooms, 3,211 living rooms and 230 unfurnished rooms. Most of the buildings were built between 1960 and 1999. Their geometric shape is a parallelepiped rectangle with a height of 2.5 meters. All the rooms have thick walls and ceilings. The interior partitions are hollow brick walls covered with plaster. The floor covering is mainly terrazzo or parquet finish glued onto a levelling layer of cement mortar. The characteristics of the buildings, as well as the interior fittings, furnishing and décor may be considered to be representative of Spanish buildings in general.

2. MEASUREMENTS

Over this period, our laboratory carried out, with the appropriate technical staff and equipment, the acoustic measurements of the airborne sound insulation of facades of the rooms in more than four thousand dwellings affected by airport noise. Approximately 50 people took part in the measuring process (physicists, engineers, architects, assistants, etc.). Eight teams took daily acoustic measurements. All these teams were specifically trained for this task by the authors of this paper. The results obtained by each team were subsequently compared.

The acoustic measurements were carried out according to ISO standard 140-5 [3]. As an evaluation criterion for the airborne sound insulation of facades we used the Standardized Level Difference $D_{ls,2m,nT}$. In order to use this criterion we needed to measure the reverberation time in the receiving room. The acoustic measuring apparatus (Type 2260 acoustic analysers, sound sources, processing software, etc.) was manufactured by B&K. The accuracy of the measuring equipment was verified periodically in accredited calibration laboratories.

Due to the large number of furnished rooms studied, our aim was to obtain an empirical function between the reverberation time and the volume of the rooms for each frequency octave band.

The reverberation time measuring equipment complies with the requirements defined in ISO 354 [4]. Reverberation times can be evaluated by using different methods. In this work the interrupted noise method has been used and the decay curves of sound pressure level, as a function of time at one point in the room after the sound source had ceased was evaluated on the interval between -5 dB and -25 dB below the initial sound pressure level. In the data analysis the abnormal decay curves were eliminated.

Most of the rooms where the acoustic measurements were carried out have a volume of less than 50 m^3. These spaces do not have diffuse acoustic field conditions, especially at low frequencies, of below 200 Hz, where room modes are well spaced. The sources of experimental errors in acoustic decay measurements are a smoothing produced by the averaging device, and a ringing of the band pass filter [5], [6], [7], [8], [9]. In the acoustic measurements taken in this work, the values of the reverberation times comply with the limits for obtaining reliable results, due to the detector and the filter [10].

To summarise, the number of rooms measured, their classification according to their volume, furnishings and use are shown in Table 1.

Table 1. Classification of rooms according to their volume and furnishings

Range of volume, m^3	Furnished rooms						Unfurnished rooms		
	Living rooms			Bedrooms					
	Nº of rooms	Volume, m^3		Nº of rooms	Volume, m^3		Nº of rooms	Volume, m^3	
10 <V <20	35	Average	16.0	1686	Average	15.6	27	Average	17.4
		Std dev	1.3		Std dev	1.3		Std dev	2.1
20 <V <30	392	Average	25.0	5233	Average	24.8	127	Average	25.3
		Std dev	1.5		Std dev	1.4		Std dev	2.6
30 <V <40	761	Average	35.1	1111	Average	34.5	43	Average	33.5
		Std dev	1.4		Std dev	1.4		Std dev	2.7
40 <V <50	1028	Average	45.0	150	Average	44.5	25	Average	46.0
		Std dev	1.4		Std dev	1.5		Std dev	2.7
50 <V <60	420	Average	54.7	43	Average	54.5	8	Average	55.3
		Std dev	1.5		Std dev	2.8		Std dev	2.5
60 <V <70	288	Average	64.8	23	Average	63.8			
		Std dev	1.4		Std dev	2.9			
70 <V <80	148	Average	74.7						
		Std dev	1.5						
80 <V <90	95	Average	84.4						
		Std dev	1.4						
90 <V <100	44	Average	95.1						
		Std dev	1.5						

Table 2 Reverberation times of furnished rooms in octave band

Range of volume, m^3	Furnished rooms			Reverberation time s, octave band width					
	Nº of rooms		Volume, m^3	125	250	500	1000	2000	4000
10 < V < 20	1721	Average	15.8	0.49	0.38	0.33	0.30	0.28	0.26
		St dev	1.4	0.15	0.11	0.10	0.09	0.08	0.07
20 < V < 30	5625	Average	24.9	0.52	0.42	0.36	0.32	0.30	0.28
		St dev	1.4	0.16	0.13	0.11	0.09	0.08	0.07
30 < V < 40	1872	Average	34.8	0.55	0.46	0.40	0.36	0.34	0.32
		St dev	1.4	0.16	0.13	0.11	0.09	0.08	0.07
40 < V < 50	1178	Average	44.7	0.60	0.50	0.45	0.40	0.38	0.35
		St dev	1.5	0.18	0.14	0.12	0.10	0.09	0.08
50 < V < 60	463	Average	54.6	0.63	0.53	0.48	0.44	0.41	0.38
		St dev	2.1	0.20	0.16	0.13	0.12	0.10	0.08
60 < V < 70	311	Average	64.3	0.62	0.55	0.50	0.45	0.43	0.39
		St dev	2.1	0.16	0.12	0.11	0.10	0.09	0.08
70 < V < 80	148	Average	74.7	0.68	0.58	0.52	0.48	0.45	0.41
		St dev	1.5	0.19	0.16	0.14	0.13	0.11	0.09
80 < V < 90	95	Average	84.4	0.72	0.62	0.55	0.51	0.48	0.43
		St dev	1.4	0.22	0.15	0.13	0.14	0.12	0.09
90 < V < 100	44	Average	95.1	0.77	0.66	0.58	0.52	0.48	0.44
		St dev	1.5	0.22	0.16	0.13	0.11	0.10	0.09

3. REVERBERATION TIME IN FURNISHED ROOMS

The furniture and decorative elements in a room produce absorption and scattering of sound. The type and amount of furniture varies widely from one room to another. The furnishing of bedrooms is, in general, different. For this reason, we first compared the results of the reverberation time obtained in bedrooms and living rooms. For each range of room volume, the results of the measurements of reverberation time in octave band are quite similar, as shown in Figures 1 and 2. The differences between the results of the reverberation time are less than 0.05 seconds in each frequency band, within the standard deviation of data. Living rooms and bedrooms are thus considered in the same category of furnished rooms.

Table 2 shows the number of furnished rooms in each volume range and the reverberation times in octave bands, together with their standard deviation. In each volume range, the measurements of the reverberation time at low frequencies show higher standard deviation than at medium and high frequencies.

Fig. 3 shows in three dimensions the reverberation time of furnished rooms as a function of the volume and frequency.

Table 3 shows two different fitting regression functions of reverberation time in furnished rooms, for each frequency octave band. In these, the independent variable is the volume of the room, V in cubic meters. Although the quadratic fitting function is slightly better than the linear one, the linear fitting function has greater practical use.

Table 3. Fitting functions of reverberation time in furnished rooms

Frequency, Hz	Linear fitting function	R^2	Quadratic fitting function	R^2
125	$T = 0.0034\ V + 0.4356$	0.9767	$T = 7.10^{-6}\ V^2 + 0.0026\ V + 0.4526$	0.9788
250	$T = 0.0034\ V + 0.3372$	0.9931	$T = -6.10^{-6}\ V^2 + 0.004\ V + 0.3236$	0.9945
500	$T = 0.0031\ V + 0.2922$	0.9819	$T = -2.10^{-5} V^2 + 0.0048\ V + 0.255$	0.9942
1000	$T = 0.0029\ V + 0.2599$	0.9796	$T = -2.10^{-5} V^2 + 0.0046\ V + 0.2239$	0.9927
2000	$T = 0.0027\ V + 0.2464$	0.9692	$T = -2.10^{-5} V^2 + 0.0048\ V + 0.2013$	0.9930
4000	$T = 0.0023\ V + 0.2344$	0.9680	$T = -2.10^{-5} V^2 + 0.0042\ V + 0.1929$	0.9950

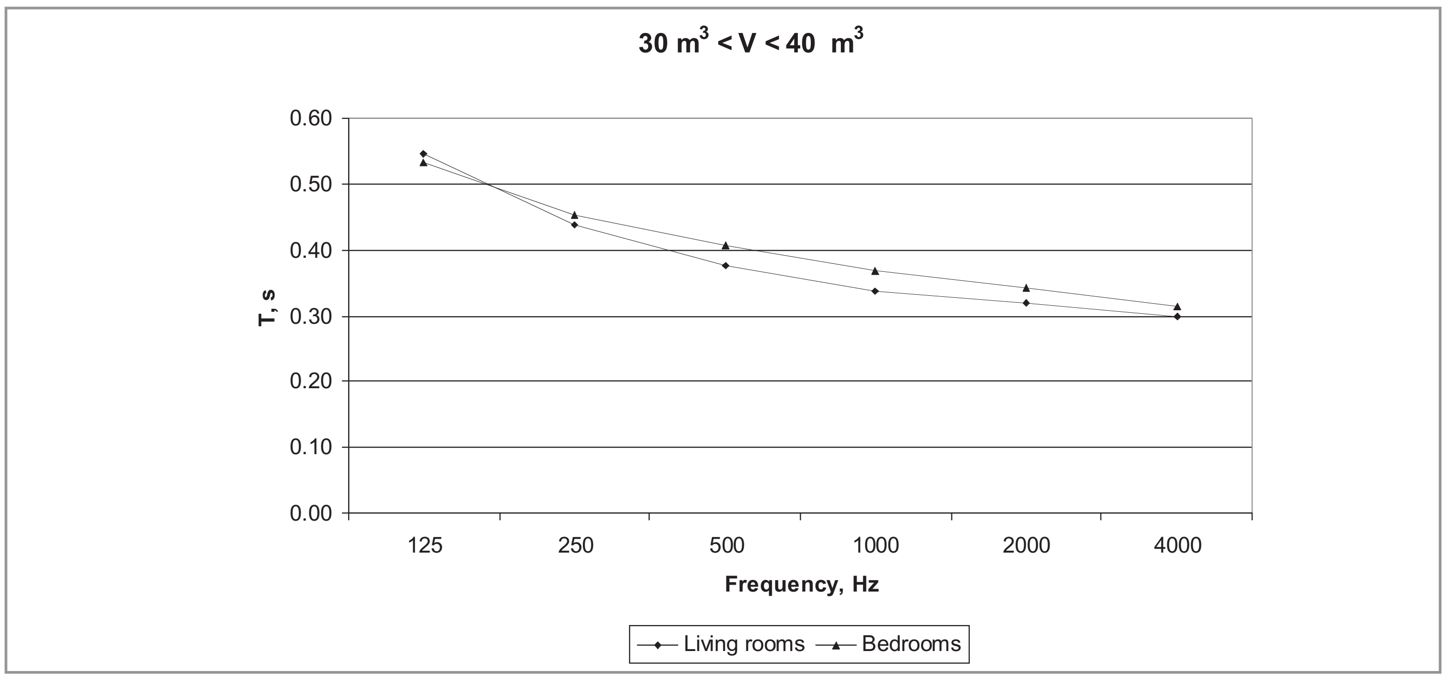

Figure 1. Comparison of reverberation time between bedrooms and living rooms as a function of frequency, $30\ m^3 < V < 40\ m^3$

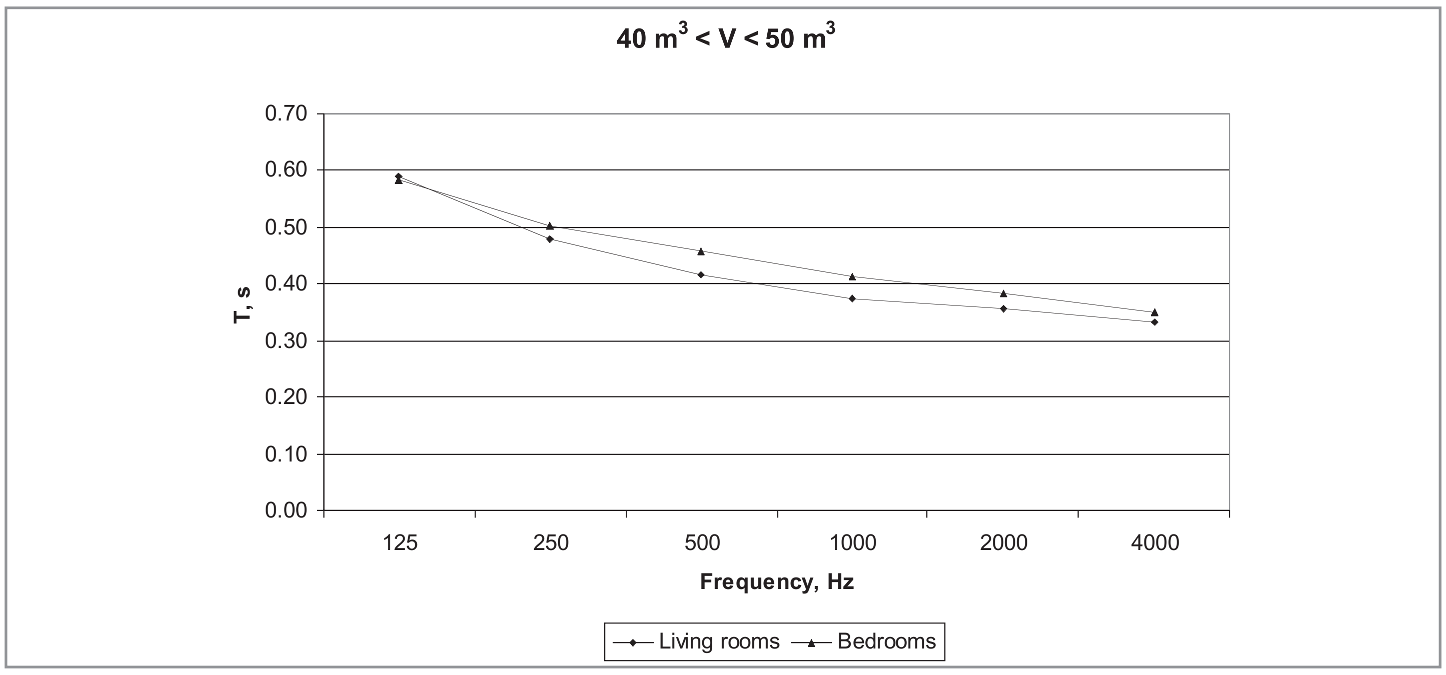

Figure 2. Comparison of reverberation time between bedrooms and living rooms as a function of frequency, $40\ m^3 < V < 50\ m^3$

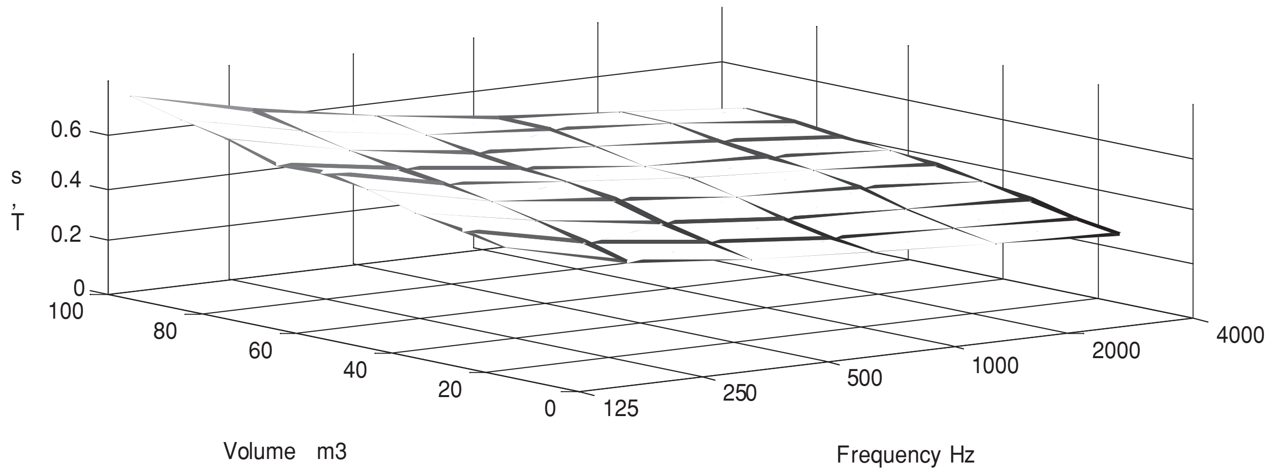

Figure 3 *The reverberation time of furnished rooms as a function of the volume and frequency*

In addition, a multiple correlation was carried out with the results obtained in furnished rooms in order to determine a relation between the reverberation time as a function of their volume and the frequency. The results are as follows:

$$T = 0.367 + 0.003\,V - 5.10^{-5}f$$
$$R^2 = 0.7748 \qquad (1)$$

Fig. 4 shows the predicted reverberation times by means of eq. (1). A reverberation plane is obtained in octave bands. In a furnished room, for each volume of room the reverberation time can be estimated in each frequency octave band.

4. REVERBERATION TIME IN UNFURNISHED ROOMS

All the unfurnished rooms where the measurements of reverberation time were taken have solid walls and ceilings and a heavy hard floor covering. Table 4 shows the number of unfurnished rooms studied in each volume range, and the average and standard deviation of volume and reverberation time measured in octave bands

The results of the reverberation time in unfurnished rooms show a standard deviation which is substantially greater than that for furnished rooms. The standard deviation of reverberation time decreases when the frequency band increases.

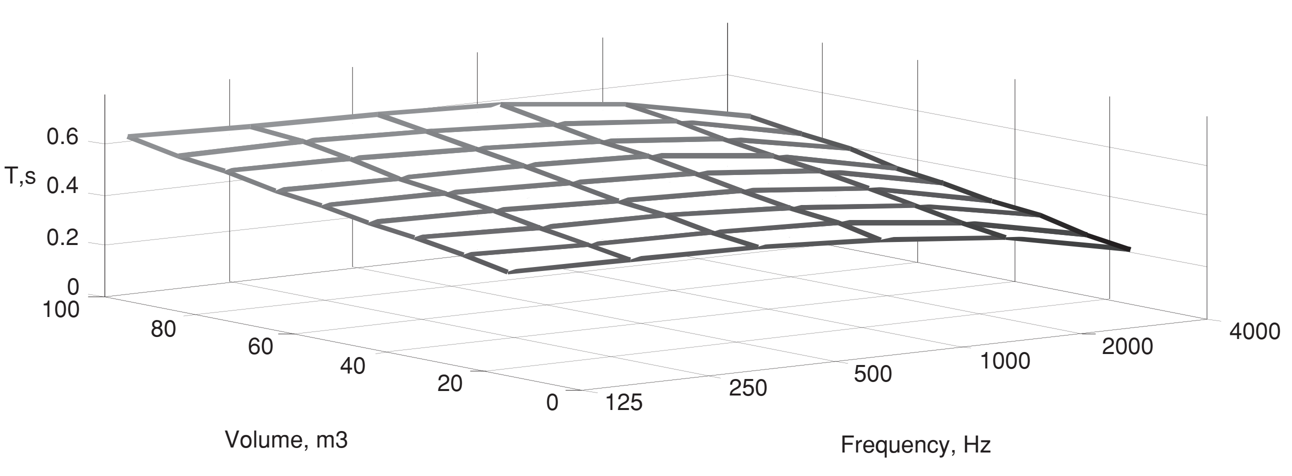

Figure 4 *Plane of reverberation time in furnished rooms obtained by multiple correlation of experimental data*

Table 4. Reverberation times of unfurnished rooms in octave band

Range of volume, m^3	Unfurnished rooms			Reverberation time s, octave band width					
	Nº of rooms		Volume, m^3	125	250	500	1000	2000	4000
10 < V < 20	27	Average	17.4	1.26	1,12	0.97	0.73	0.64	0.55
		St dev	2.1	0.56	0.45	0.34	0.24	0.17	0.14
20 < V < 30	127	Average	25.3	1.84	1.77	1.46	1.13	0.95	0.83
		St dev	2.6	0.69	0.58	0.43	0.31	0.25	0.18
30 < V < 40	43	Average	33.5	1.91	1.86	1.50	1.17	0.96	0.78
		St dev	2.7	0.89	0.81	0.60	0.43	0.31	0.23
40 < V < 50	25	Average	46.0	2.10	2.00	1.72	1.53	1.32	1.11
		St dev	2.7	0.57	0.52	0.48	0.46	0.43	0.36
50 < V < 60	8	Average	55.3	2.11	2.16	1.82	1.70	1.51	1.23
		St dev	2.5	0.71	0.57	0.62	0.40	0.39	0.34

Table 5. Fitting functions of reverberation time in unfurnished rooms

Frequency, Hz	Linear fitting function	R^2	Quadratic fitting function	R^2
125	T = 0.0197 V + 1.1463	0.7521	$T = -9.10^{-4} V^2 + 0.0875 V + 0.0824$	0.9386
250	T = 0.0232 V + 0.9598	0.7924	$T = -9.10^{-4} V^2 + 0.0863 V - 0.0309$	0.9151
500	T = 0.0199 V + 0.7882	0.8559	$T = -6.10^{-4} V^2 + 0.0624 V + 0.1211$	0.9375
1000	T = 0.0241 V + 0.3949	0.9558	$T = -2.10^{-4} V^2 + 0.0411 V + 0.1294$	0.9655
2000	T = 0.0219 V + 0.2977	0.9648	$T = -10^{-5} V^2 + 0.023 V + 0.2814$	0.9648
4000	T = 0.0171 V + 0.2934	0.9291	$T = -3.10^{-5} V^2 + 0.019 V + 0.2633$	0.9293

Table 5 shows two fit equations of reverberation times of unfurnished rooms studied as a function of their volume for each frequency band, and the coefficient of multiple determination R^2.

With the results obtained in unfurnished rooms a multiple correlation was carried out to determine a relation between the reverberation time as a function of the rooms' volume and the frequency. The results are as follows:

$$T = 0.949 + 0.021\,V - 2.10^{-4} f$$
$$R^2 = 0.8254 \qquad (2)$$

A reverberation plane is obtained in octave bands. In an unfurnished room, for each room volume the reverberation time can be estimated for each frequency octave band.

As can be seen in Tables 2 and 4, there are considerable differences between the reverberation times measured in furnished and unfurnished rooms. For example, Fig. 5 shows this clearly in the range of volume between 20 and 30 m^3.

5. EQUIVALENT SOUND ABSORPTION AREA IN ROOMS

The equivalent sound absorption area of a room A, expressed in m^2, is the hypothetical area of a totally absorbing surface without diffraction effect which, if it were the only absorbing element in the room, would give the same reverberation time as the room under consideration. Standard EN 12354-6: 2003 [11], which covers the calculation of the equivalent sound absorption area and the reverberation time in enclosed

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spaces, assumes that the sound field is diffused. The total equivalent sound absorption area, A, is determined from the reverberation time

$$A = \frac{0{,}16V\,(1 - \psi)}{T} \qquad (3)$$

where

T is the reverberation time, in seconds; V is the volume of the empty room, in cubic meters, without the objects and fittings present; ψ is the object fraction (the ratio of the sum of the volumes of all objects in the room to the volume of the empty room).

The model is applicable to regularly-shaped rooms in buildings with a reasonable distribution of absorbing material and some assorted objects, either hard or absorbing. In such rooms, the absorption by air can be neglected. In the majority of the furnished rooms studied in this work, the object fraction is approximately $\psi = 0.1$.

In bedrooms and living rooms the sound field is usually non-diffuse, especially at low frequencies, and the sound absorption is not uniformly distributed. The furniture in a room produces an appreciable effect on the distribution of spatial sound pressure levels, which is more marked as the frequency increases [12].

According to standard EN 12354-6: 2003, the product of the reverberation time and the total equivalent sound absorption area of a room is a constant in each frequency. The total equivalent sound absorption area and its standard deviation were obtained in each range of volume of the rooms by means of the reverberation time measured and its standard deviation in each frequency band. Tables 6 and 7 show the total equivalent sound absorption area of furnished and unfurnished rooms in dwellings. In furnished rooms, the object fraction $\psi = 0.1$ was taken into account. Table 8 shows the linear fitting equations of the total sound absorption area time as a function of the volume for each frequency octave band for furnished and unfurnished rooms.

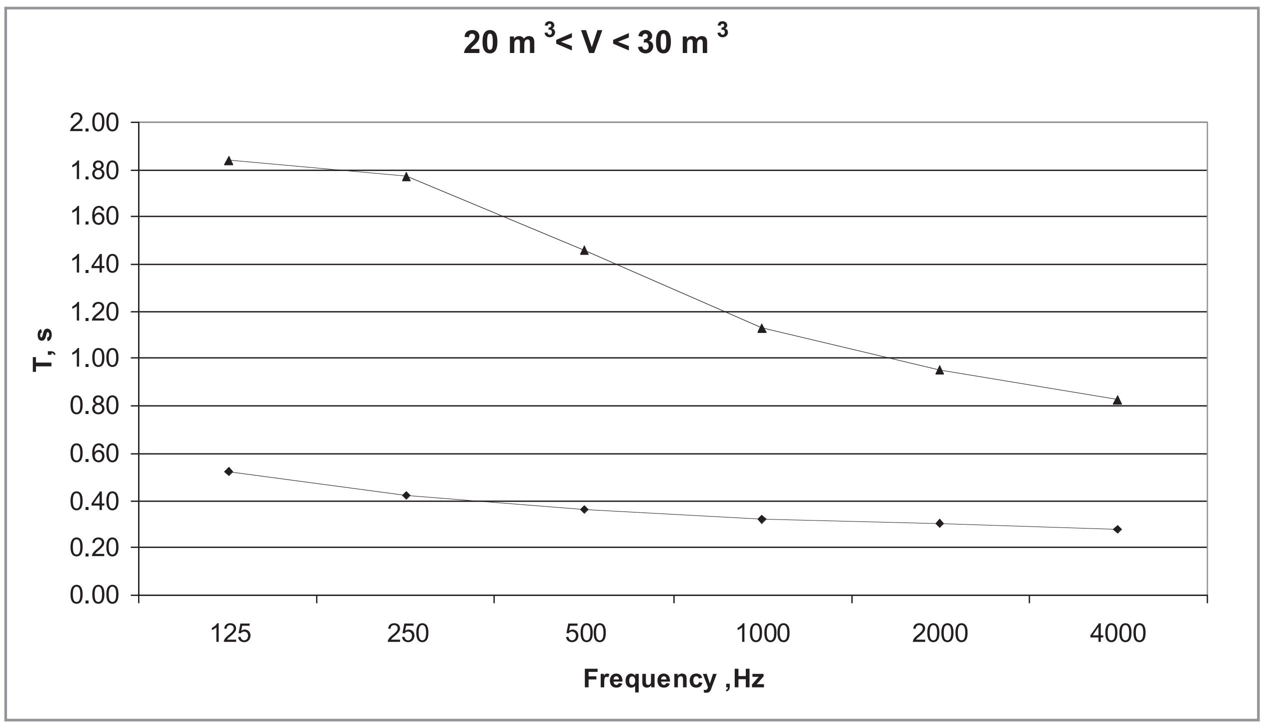

Figure 5. Comparison of reverberation times between furnished and unfurnished rooms, 20 m^3 < V < 30 m^3

Table 6. Total equivalent sound absorption area of furnished rooms in dwellings, $A_{furnished}$ in m^2, taking into account the object fraction ψ

Range of volume, m^3	Total equivalent sound absorption area, $A_{\text{furnished}}$, m^2, octave band width							
	Nº of rooms	Frequency, Hz	125	250	500	1000	2000	4000
10 < V < 20	1721	$A_{\text{fur av-sd}}$	6.7	8.5	9.9	10.6	11.2	11.9
		$A_{\text{fur average}}$	4.6	6.0	6.9	7.6	8.1	8.8
		$A_{\text{fur av +sd}}$	3.6	4.6	5.3	5.9	6.4	6.9
20 < V < 30	5625	$A_{\text{fur av-sd}}$	10.0	12.2	14.3	15.7	16.0	16.7
		$A_{\text{fur average}}$	6.9	8.5	10.0	11.2	11.9	12.8
		$A_{\text{fur av+sd}}$	5.3	6.6	7.7	8.7	9.5	10.4
30 < V < 40	1872	$A_{\text{fur av-sd}}$	13.0	15.0	17.0	18.5	19.1	19.7
		$A_{\text{fur average}}$	9.1	10.9	12.5	13.9	14.7	15.7
		$A_{\text{fur av+sd}}$	7.0	8.6	9.9	11.2	12.0	13.0
40 < V < 50	1178	$A_{\text{fur av-sd}}$	15.3	18.0	19.6	21.7	22.4	23.6
		$A_{\text{fur average}}$	10.7	12.9	14.3	16.1	16.9	18.4
		$A_{\text{fur av+sd}}$	8.3	10.0	11.3	12.8	13.6	15.1
50 < V < 60	463	$A_{\text{fur av-sd}}$	18.2	21.2	22.4	24.3	25.5	26.6
		$A_{\text{fur average}}$	12.5	14.8	16.4	17.9	19.2	20.7
		$A_{\text{fur av+sd}}$	9.5	11.4	12.9	14.1	15.4	16.9
60 < V < 70	311	$A_{\text{fur av-sd}}$	20.0	21.4	23.9	26.2	27.1	29.4
		$A_{\text{fur average}}$	14.9	16.8	18.5	20.6	21.5	23.7
		$A_{\text{fur av+sd}}$	11.9	13.9	15.1	16.9	17.9	19.9
70 < V < 80	148	$A_{\text{fur av-sd}}$	22.0	25.4	28.1	30.6	31.6	33.8
		$A_{\text{fur average}}$	15.8	18.6	20.7	22.4	23.9	26.2
		$A_{\text{fur av+sd}}$	12.3	14.6	16.4	17.7	19.2	21.5
80 < V < 90	95	$A_{\text{fur av-sd}}$	24.3	25.9	29.0	32.5	33.4	36.0
		$A_{\text{fur average}}$	16.9	19.6	22.1	23.8	25.3	28.3
		$A_{\text{fur av+sd}}$	12.9	15.8	17.9	18.8	20.4	23.3
90 < V < 100	44	$A_{\text{fur av-sd}}$	25.1	27.3	30.8	33.4	35.9	39.1
		$A_{\text{fur average}}$	17.8	20.8	23.6	26.3	28.5	31.1
		$A_{\text{fur av+sd}}$	13.8	16.7	19.2	21.8	23.7	25.9

6. CONCLUSIONS

From the wide range of fieldwork done in rooms with masonry walls, ceilings, and heavy floor covering we may reach the following conclusions:

The reverberation times measured are quite similar in bedrooms and living rooms, in rooms within the same volume range, and decrease fairly uniformly as the frequency increases. More over, in each frequency band the greater the volume of the room, the greater the reverberation time. The sound absorption is caused basically by the furnishing and décor, particularly at medium and high frequencies.

The results of reverberation time in unfurnished rooms show a standard deviation which is considerably greater than that for furnished rooms.

The results of this extensive work allow us to predict accurately the reverberation time and the total equivalent sound absorption area in these kinds of spaces as a function of their volume and frequency. The data may be useful for improving the accuracy of calculation models to estimate the reverberation time of enclosed spaces.

The use of the linear fitting functions of the reverberation time obtained in this work in the evaluation of airborne sound insulation between rooms, impact sound insulation of floors, and airborne sound insulation of facades, could represent a considerable saving in the time involved in taking *in situ* acoustic measurements, without compromising the accuracy of the results.

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[2] EN ISO 140 – 7 :1998, *Acoustics –Measurement of sound insulation in buildings and of building elements – Part 7: Field measurements of impact sound insulation of floors*. (ISO 140-7: 1998).

[3] EN ISO 140 – 5: 1998, *Acoustics – Measurement of sound insulation in buildings and of building elements – Part 5: Field measurements of airborne sound insulation of façade elements and facades*. (ISO 140-5:1998).

Table 7. Total equivalent sound absorption area of unfurnished rooms in dwellings, $A_{unfurnished}$ in m^2.

Range of volume, m^3	Total equivalent sound absorption area, $A_{unfurnished}$, m^2, octave band width							
	Nº of rooms	Frequency, Hz	125	250	500	1000	2000	4000
10 < V < 20	27	$A_{unfur\ av\text{-}sd}$	4.0	4.2	4.4	5.7	6.0	6.8
		$A_{unfur\ average}$	2.2	2.5	2.9	3.8	4.4	5.1
		$A_{unfur\ av+sd}$	1.8	1.8	2.1	2.9	3.4	4.0
20 < V < 30	127	$A_{unfur\ av\text{-}sd}$	3.5	3.4	3.9	4.9	5.8	6.2
		$A_{unfur\ average}$	2.2	2.3	2.8	3.6	4.3	4.9
		$A_{unfur\ av+sd}$	1.6	1.7	2.1	2.8	3.4	4.0
30 < V < 40	43	$A_{unfur\ av\text{-}sd}$	5.2	5.1	5.9	7.2	8.3	9.8
		$A_{unfur\ average}$	2.8	2.9	3.6	4.6	5.6	6.9
		$A_{unfur\ av+sd}$	1.9	2.0	2.6	3.4	4.2	5.3
40 < V < 50	25	$A_{unfur\ av\text{-}sd}$	4.8	5.0	5.9	6.9	8.3	9.8
		$A_{unfur\ average}$	3.5	3.7	4.3	4.8	5.6	6.6
		$A_{unfur\ av+sd}$	2.8	2.9	3.3	3.7	4.2	5.0
50 < V < 60	8	$A_{unfur\ av\text{-}sd}$	6.3	5.6	7.3	6.8	7.9	9.9
		$A_{unfur\ average}$	4.2	4.1	4.9	5.2	5.9	7.2
		$A_{unfur\ av+sd}$	3.1	3.2	3.6	4.2	4.7	5.6

Table 8. Linear fitting functions of the total equivalent sound absorption area, A in m^2, of furnished and unfurnished rooms in dwellings, taking into account the fraction object ψ in furnished rooms.

Octave-band centre frequency, Hz	Furnished rooms; Range of volume, 10 m^3 < V <100 m^3		Unfurnished rooms, Range of volume, 10 m^3 < V < 60 m^3	
	Linear fitting function	R^2	Linear fitting function	R^2
125	A = 0.1679 V + 2.9369	0.9758	A = 0.0552 V + 1.022	0.9592
250	A = 0.1871 V + 4.0647	0.9819	A = 0.0487 V + 1.3569	0.9202
500	A = 0.2078 V + 4.7207	0.9887	A = 0.0574 V + 1.6334	0.9511
1000	A = 0.2255 V + 5.3999	0.9872	A = 0.0414 V + 2.927	0.8645
2000	A = 0.2429V + 5.6025	0.9904	A = 0.0439V + 3.5644	0.7889
4000	A = 0.2726 V + 5.6883	0.9934	A = 0.0607 V + 3.9692	0.7467

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FORT WORTH GAS RIGS

With Fort Worth sitting on one of the largest natural gas fields in the United States, 50-metre-high drilling rigs are rising over golf courses, churchyards, even tree-lined neighbourhoods. But not everyone is celebrating the natural gas bonanza, despite the 55,000 new jobs and extra US$5.2 billion annually it is bringing to the north Texas economy. Once confined to the prairies, oil and gas exploration has gone urban. In Fort Worth, Los Angeles and other densely populated places, this exploration sometimes pits neighbour against neighbour, forcing them to choose between preserving a tranquil neighbourhood or cashing the monthly royalty cheques a gas or oil well provides. In some cases, entire neighbourhoods are organising to keep the wells out. They are worried about the drilling and extraction noise - which can sound like a jet engine - heavy truck traffic, decreased property values and explosions. An XTO Energy worker was killed last year in a gas well explosion in nearby Forrest Hill. “Believe me, if people weren’t getting money, nobody would want this” said Don Young, who founded Fort Worth Citizens Against Neighbourhood Drilling Ordinance. With U.S. demand for natural gas soaring, the city has 500 active gas wells and permits for an additional 225, including 70 now being drilled. Drilling takes about a month of round-the-clock work, first vertically and then horizontally into a rock formation called the Barnett Shale thousands of metres below. Then comes a week or so of “fracking” - the hydraulic fracturing process that breaks through the dense, black rock and unlocks the natural gas within. Fort Worth initially allowed gas wells within about 90 metres of homes but recently extended the boundary to up to 300 metres - depending on the permit type - after getting noise complaints. The city also set noise limits and established fines of up to US$2,000 a day for violations. Mayor Mike Moncrief said the ordinance aims to protect residents’ safety and quality of life during a “once-in-a-lifetime” opportunity.