SIMPLIFIED METHOD TO ESTIMATE REVERBERATION TIME IN DWELLINGS.

Leonardo Meza*[1], and Manuel Recuero[2]

[1]Escuela de Construcción Civil. Facultad de Ingeniería.
Pontificia Universidad Católica de Chile.
Av. Vicuña Mackena 4860, Macul, Santiago, Chile.
lmeza@insia.upm.es

[2] Grupo de Investigación en Instrumentación y Acústica Aplicada GI^2A^2.
Universidad Politécnica de Madrid - INSIA.
Campus Sur UPM, Ctra. Valencia km.7, 28031, Madrid, España.
manuel.recuero@upm.es

Abstract

This research presents a simplified model to obtain reverberation time in furnished rooms in dwellings.
Using the results of the reverberation time obtained durin and "in situ" measurement campaign, a mean value was obtained in function of the room volume and use.
The results obtained from the acoustic measures show that the rooms with parallelepiped shape, increase the reverberation time with the volume. This does not happen in rooms with irregular shape. In general, the reverberation time decreases when the frequency increases.
This research allows to predict the reverberation time for each frecuency band in function of the room's volume.

INTRODUCTION

Reverberation time is one of the most utilised descriptors in architectural and building acoustics. In the latter, so as to determine both air noise insulation and impact noise, it is necessary to know the reverberation time of the recipient area in order to carry out corrections to the measures taken.

One way of simplifying the aforementioned trials could be via reverberation time estimates throughout frequency bands in the recipient area on the basis of their volume.

In order to be able to estimate this objective in this paper, the results of one in situ measurement campaign for reverberation time in 502 areas, all furnished, from an acoustic measurement campaign carried out between March and July in 2005 in the city of Malaga located in southern Spain are shown.

Measurements were taken in 174 homes where 204 living rooms and 296 bedrooms were tested. The years the properties were built go from 1940 to 2001. The volume of the living rooms tested is between 20.2 and 111 m^3 with an average of 62.6 m^3, and the bedrooms from 14.3 to 66.6 m^3 with an average of 29.8 m^3.

INSTRUMENTATION USED AND MEASUREMENTS.

The measurements were carried out following the methodology described in the ISO 140-5 [3] standard and evaluated using the ISO 717-1 [4] standard. In the measurement campaign specific equipment for field measures were used: Brüel & Kjaer sound source type 4237 with serial number 2481341; Brüel & Kjaer sound Level Metre type 2260 with serial number 2248349; Brüel & Kjaer pre-polarized microphone type 4189 with serial number 2299594; Brüel & Kjaer amplifier type 2716 with serial number 24860544; Brüel & Kjaer calibrator type 4231 with serial number 2477748; DBX equalizer 131; AKG wireless microphone type WMS 4000; and environmental conditions meter. All these devices were calibrated in authorised laboratories.

Volume (m^3)	Living Rooms			Bedrooms		
	Numbers	Volume (m^3)	Standard Desviation (SD)	Numbers	Volume (m^3)	Standard Desviation (SD)
10 < V < 20	-	-	-	14	17,8	1,8
20 < V < 30	6	25,2	3,3	159	25,5	2,8
30 < V < 40	21	35,0	3,0	100	34,2	2,8
40 < V < 50	43	44,8	2,7	18	44,3	3,0
50 < V < 60	6	56,1	2,9	35	55,7	2,9
60 < V < 70	25	63,5	3,1	1	66,6	-
70 < V < 80	22	76,2	2,6	-	-	-
80 < V < 90	28	84,8	2,9	-	-	-
90 < V < 100	15	96,6	2,7	-	-	-

TABLE Nº1: Classification of areas according to use and volume

REVERBERATION TIME IN LIVING ROOMS.

The areas given over to living rooms normally have a greater amount of furniture than bedrooms, with their shape usually being more irregular than bedrooms which are parallelepiped.

With regards to furniture, this affects greater sound absorption and the parallelepiped shape of the bedrooms favours the formation of static waves.

For this reason both types of area were analysed separately. In figures 1 to 4 the results of the average reverberation time for each volume range in third octave bands in the form of regression lines from numeric values are shown.

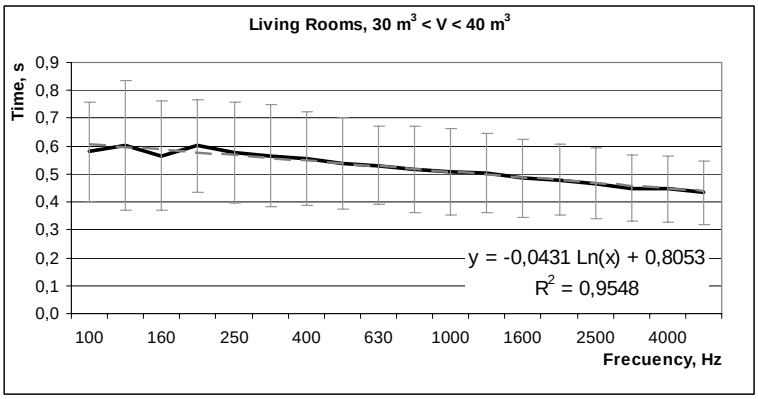

Figure Nº 1: Reverberation Time in Living Rooms with volumes between 30 and 40 m^3.

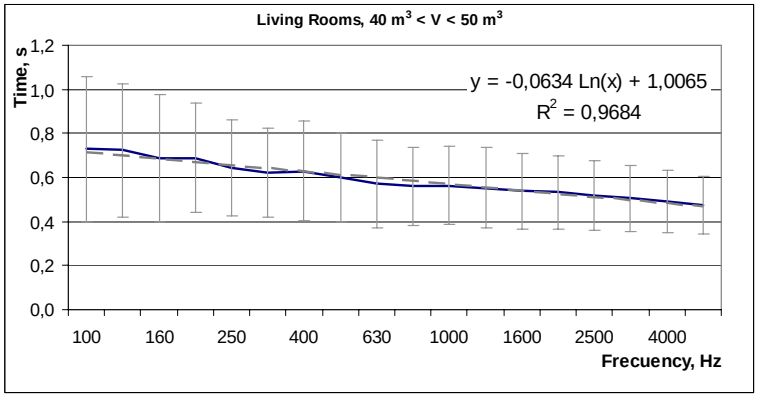

Figure Nº 2: Reverberation Time in Living Rooms with volumes between 40 and 50 m^3.

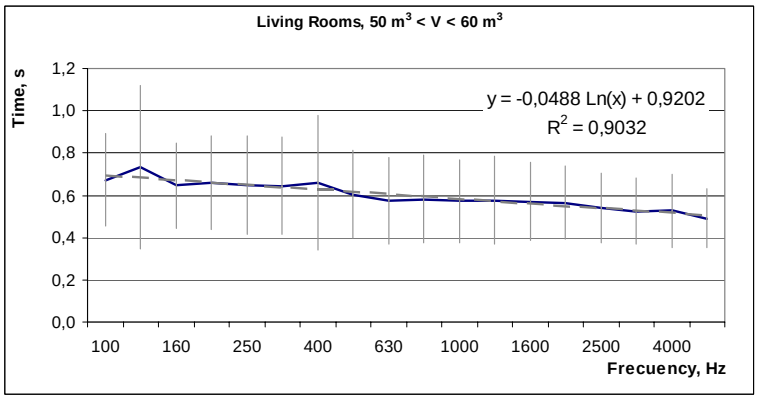

Figure Nº 3: Reverberation Time in Living Rooms with volumes between 50 and 60 m^3.

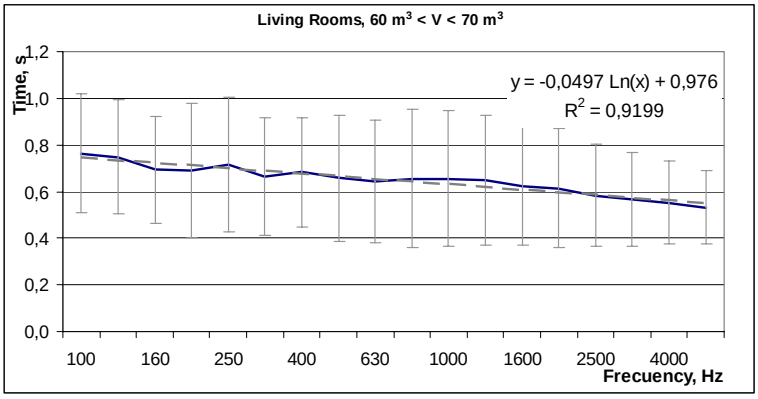

Figure Nº 4: Reverberation Time in Living Rooms with volumes between 60 and 70 m^3.

Tables 2 and 3 show the results from living rooms where, for different volume ranges, a logarithmic equation allowing the Reverberation Time for each octave band to be determined was obtained. The average obtained from measurements carried out is also shown.

Volume (m^3)	Rooms	Meand	Standard Desviation	Lineal Function	R^2
20 - 30	6	25,2	3,3	T = - 0,0261 Ln(F) + 0,5435	R^2 = 0,6683
30 - 40	21	35,0	3,0	T = - 0,0431Ln(F) + 0,8053	R^2 = 0,9544
40 - 50	43	44,8	2,7	T = - 0,0634 Ln(F) + 1,0065	R^2 = 0,9683
50 - 60	35	55,7	2,9	T = - 0,0488 Ln(F) + 0,9202	R^2 = 0,9032
60 - 70	25	63,5	3,1	T = - 0,0497 Ln(F) + 0,9760	R^2 = 0,9199
70 - 80	22	76,2	2,6	T = - 0,0749 Ln(F) + 0,6941	R^2 = 0,7790
80 - 90	28	84,8	2,9	T = - 0,0304 Ln(F) + 0,7729	R^2 = 0,7760
90 - 100	15	96,6	2,7	T = - 0,0435 Ln(F) + 0,8552	R^2 = 0,7826

TABLE Nº2: Living Room Prediction Equation.

Volume (m^3)		100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
20 - 30	Mean	0,38	0,47	0,46	0,40	0,39	0,39	0,39	0,36	0,36	0,35	0,36	0,35	0,34	0,35	0,34	0,34	0,33	0,33
	SD	*0,07*	*0,14*	*0,10*	*0,10*	*0,09*	*0,11*	*0,15*	*0,10*	*0,13*	*0,10*	*0,11*	*0,11*	*0,11*	*0,10*	*0,10*	*0,09*	*0,09*	*0,09*
30 - 40	Mean	0,58	0,60	0,56	0,60	0,58	0,57	0,55	0,54	0,53	0,52	0,51	0,50	0,48	0,48	0,47	0,45	0,45	0,43
	SD	*0,18*	*0,23*	*0,20*	*0,17*	*0,18*	*0,18*	*0,17*	*0,16*	*0,14*	*0,16*	*0,16*	*0,14*	*0,14*	*0,13*	*0,13*	*0,12*	*0,12*	*0,11*
40 - 50	Mean	0,73	0,72	0,69	0,69	0,64	0,62	0,63	0,60	0,57	0,56	0,56	0,55	0,54	0,53	0,52	0,50	0,49	0,48
	SD	*0,33*	*0,30*	*0,29*	*0,25*	*0,22*	*0,20*	*0,23*	*0,20*	*0,20*	*0,18*	*0,18*	*0,18*	*0,17*	*0,17*	*0,16*	*0,15*	*0,14*	*0,13*
50 - 60	Mean	0,67	0,73	0,65	0,66	0,65	0,65	0,66	0,60	0,58	0,58	0,57	0,58	0,57	0,56	0,54	0,53	0,53	0,49
	SD	*0,22*	*0,39*	*0,20*	*0,22*	*0,23*	*0,23*	*0,32*	*0,21*	*0,20*	*0,21*	*0,20*	*0,21*	*0,18*	*0,17*	*0,16*	*0,16*	*0,17*	*0,14*
60 - 70	Mean	0,76	0,75	0,69	0,69	0,72	0,67	0,68	0,66	0,64	0,66	0,66	0,65	0,62	0,61	0,58	0,57	0,55	0,53
	SD	*0,26*	*0,25*	*0,23*	*0,29*	*0,29*	*0,25*	*0,24*	*0,27*	*0,26*	*0,30*	*0,29*	*0,28*	*0,25*	*0,26*	*0,22*	*0,20*	*0,18*	*0,16*
70 - 80	Mean	0,80	0,71	0,65	0,65	0,55	0,53	0,52	0,50	0,49	0,48	0,49	0,47	0,47	0,47	0,46	0,44	0,43	0,42
	SD	*0,24*	*0,26*	*0,19*	*0,25*	*0,20*	*0,18*	*0,20*	*0,18*	*0,18*	*0,18*	*0,17*	*0,16*	*0,16*	*0,15*	*0,15*	*0,14*	*0,13*	*0,12*
80 - 90	Mean	0,65	0,58	0,60	0,64	0,59	0,58	0,60	0,59	0,59	0,57	0,57	0,58	0,57	0,57	0,54	0,52	0,50	0,48
	SD	*0,09*	*0,16*	*0,13*	*0,22*	*0,17*	*0,18*	*0,20*	*0,16*	*0,23*	*0,19*	*0,21*	*0,23*	*0,22*	*0,19*	*0,16*	*0,14*	*0,13*	*0,13*
90 - 100	Mean	0,63	0,67	0,63	0,69	0,65	0,61	0,57	0,54	0,53	0,53	0,56	0,54	0,54	0,54	0,52	0,52	0,50	0,49
	SD	*0,14*	*0,17*	*0,16*	*0,17*	*0,14*	*0,15*	*0,14*	*0,15*	*0,15*	*0,14*	*0,13*	*0,13*	*0,13*	*0,13*	*0,12*	*0,12*	*0,11*	*0,10*

TABLE Nº3: Average Reverberation Time in Living Rooms according to volume.

4. REVERBERATION TIME IN BEDROOMS.

Figures 5 to 7 show the reverberation time results measured in normal furnished bedrooms according to volume range.

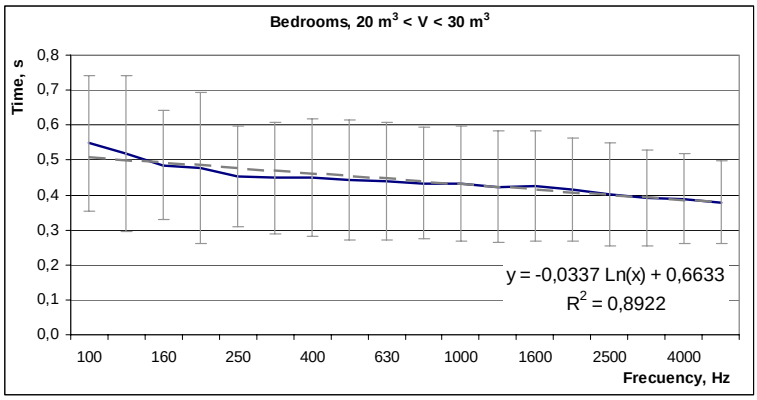

Figure Nº 5: Reverberation Time in Bedrooms with a volume between 20 and 30 m^3.

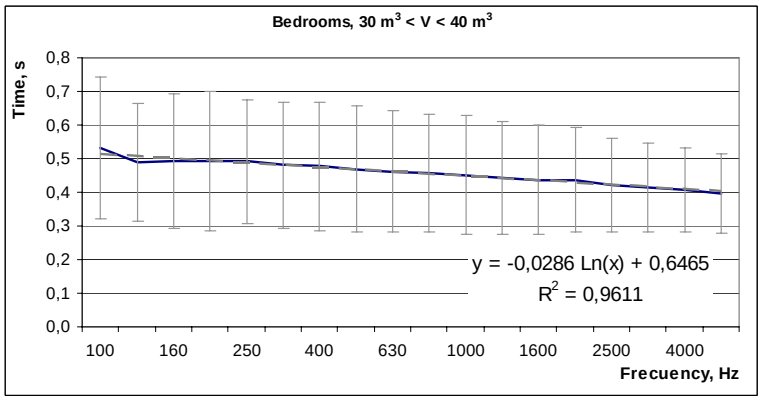

Figure Nº 5: Reverberation Time in Bedrooms with a volume between 30 and 40 m^3.

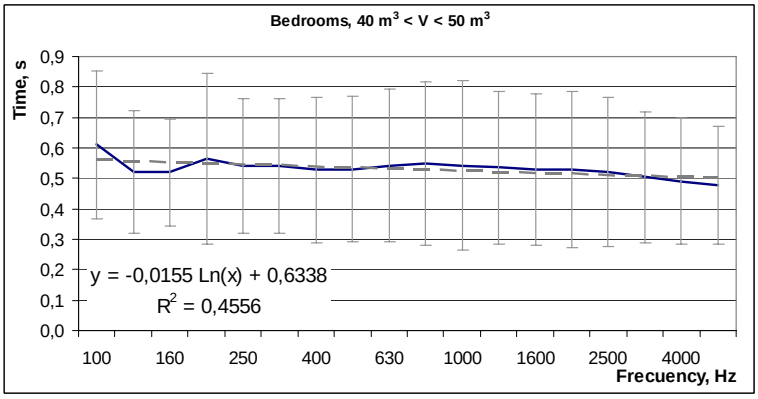

Figure Nº 6: Reverberation Time in Bedrooms with a volume between 40 and 60 m^3.

Tables 4 and 5 show results obtained from bedrooms where, for different volume ranges, a logarithmic equation allowing the Reverberation Time for each octave band to be determined was obtained. The average obtained from measurements carried out is also shown.

Volume (m^3)	Rooms	Meand	Standard Desviation	Lineal Function	R^2
10 - 20	15	17,8	1,8	T = - 0,0333 Ln(F) + 0,6306	R^2 = 0,8257
20 - 30	159	25,5	2,8	T = - 0,0337 Ln(F) + 0,6633	R^2 = 0,8922
30 - 40	100	34,2	2,8	T = - 0,0286 Ln(F) + 0,6465	R^2 = 0,9611
40 - 50	18	44,3	3,0	T = - 0,0155 Ln(F) + 0,6338	R^2 = 0,4556
50 - 60	6	56,1	2,9	T = - 0,0613 Ln(F) + 0,8802	R^2 = 0,7384
60 - 70	1	66,6			

TABLE Nº4: Bedroom Prediction Equation.

Volume (m^3)		100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
10 - 20	Media	0,51	0,49	0,49	0,45	0,42	0,40	0,40	0,41	0,41	0,40	0,40	0,41	0,39	0,40	0,37	0,36	0,36	0,35
	SD	0,25	0,27	0,16	0,14	0,12	0,18	0,13	0,13	0,16	0,13	0,12	0,12	0,11	0,11	0,11	0,11	0,11	0,11
20 - 30	Media	0,55	0,52	0,49	0,48	0,45	0,45	0,45	0,44	0,44	0,43	0,43	0,42	0,42	0,41	0,40	0,39	0,39	0,38
	SD	0,19	0,22	0,16	0,22	0,15	0,16	0,17	0,17	0,17	0,16	0,16	0,16	0,16	0,15	0,15	0,14	0,13	0,12
20 - 30	Media	0,53	0,49	0,49	0,49	0,49	0,48	0,48	0,47	0,46	0,46	0,45	0,44	0,44	0,44	0,42	0,41	0,41	0,40
	SD	0,21	0,17	0,20	0,21	0,18	0,19	0,19	0,19	0,18	0,18	0,18	0,17	0,16	0,15	0,14	0,13	0,12	0,12
30 - 40	Media	0,61	0,52	0,52	0,56	0,54	0,54	0,53	0,53	0,54	0,55	0,54	0,54	0,53	0,53	0,52	0,50	0,49	0,48
	SD	0,24	0,20	0,18	0,28	0,22	0,22	0,24	0,24	0,25	0,27	0,28	0,25	0,25	0,26	0,25	0,21	0,21	0,19
40 - 50	Media	0,75	0,56	0,53	0,56	0,55	0,51	0,47	0,47	0,42	0,46	0,43	0,44	0,43	0,43	0,41	0,40	0,40	0,39
	SD	0,30	0,14	0,08	0,11	0,12	0,10	0,09	0,06	0,05	0,09	0,07	0,08	0,08	0,07	0,05	0,05	0,04	0,03

TABLE Nº5: Average Reverberation Time in bedrooms according to volume.

5. CONCLUSIONS

The classification of the trials carried out as per area use clearly shows that in bedrooms (Figure Nº 9), the greater the volume ranges the greater Reverberation Time, a displacement being produced in parallel with the curve and which does not occur with living rooms (Figure Nº 8); this is probably due to the latter's more irregular shape and the greater amount of furniture which increase sound absorption.

The use of estimation equations for Reverberation Time of a real area allows the measurement methodologies to be simplified without prejudicing the trial results obtained for different air noise and impact noise levels.

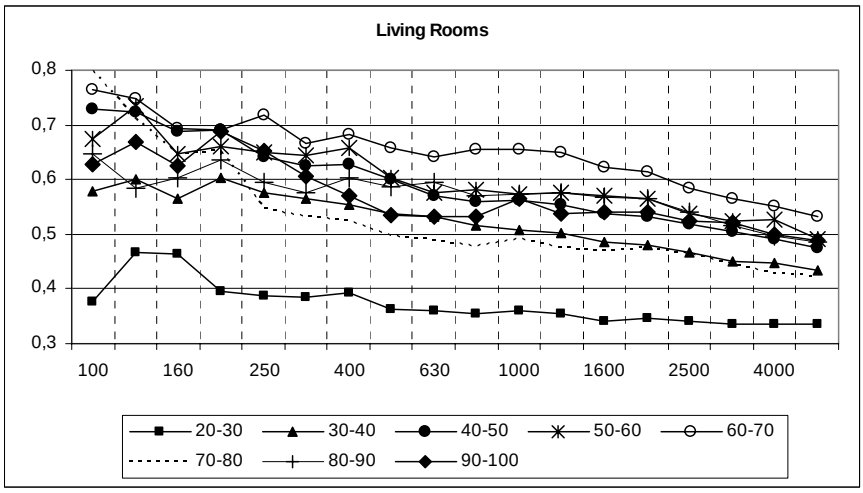

Figure Nº 8: Reverberation Time in Living Rooms. Average Values from each volume range.

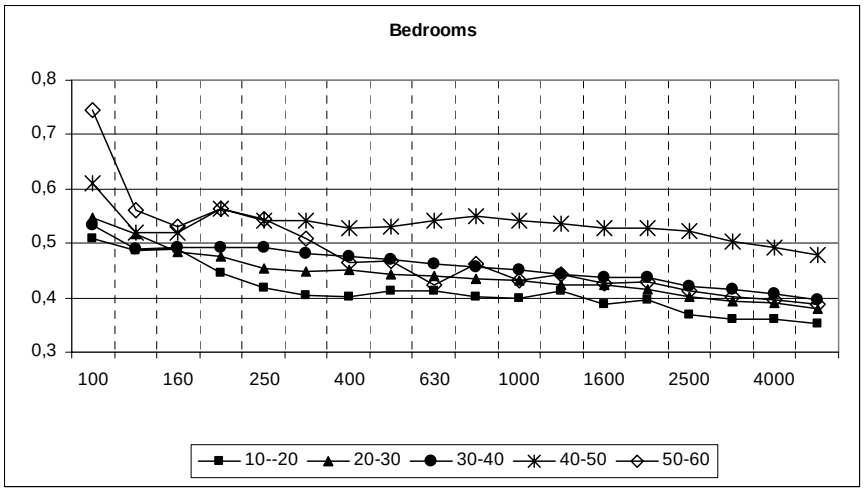

Figure Nº 9: Reverberation Time in Bedrooms. Average Values from each volume range.

REFERENCES

[1] Díaz, C. y Pedrero, A. *The reverberation time of furnished rooms in dwellings*. Journal of Applied Acoustics, Volume 66, Number 8, Agoust 2006, Pages 945-956

[2] ISO 140-4:1999 *Acoustics - Measurement of sound insulation in buildings and of building elements Part 4: Field measurements of airborne sound insulation between rooms.*

[3] ISO 140-5:1999 *Acoustics - Measurement of sound insulation in buildings and of building elements Part 5: Field measurements of airborne sound insulation of facade elements and facades*.

[4] ISO 717-1:1996 *Acoustics -- Rating of sound insulation in buildings and of building elements -- Part 1: Airborne sound insulation.*

[5] Josse. R. (1975). *La acústica en la construcción*. Editorial Gustavo Pili, S.A.

[6] Maekawa, Z. y Lord, P. (1997). *"Environmental and Architectural Acoustics"*. E&FN SPON.

[7] Meisser, M. (1973). *Acústica de los Edificios.* Editores Técnicos Asociados, S.A.