ICSV13 - Vienna
The Thirteenth International Congress on Sound and Vibration
Vienna, Austria, July 2-6, 2006

REPRODUCIBILITY IN INTERLABORATORY IMPACT SOUND INSULATION MEASUREMENTS

Antonio Pedro O. Carvalho

Laboratory of Acoustics, Faculty of Engineering, University of Porto
R. Dr. Roberto Frias, P-4200-465 Porto, Portugal
carvalho@fe.up.pt

Abstract

This paper presents the results of an interlaboratory comparison test concerning the impact sound insulation for a concrete slab floor to determine the reproducibility for the weighted normalized impact sound pressure level *L'n,w* and for all the involved main parameters (reverberation time and impact normalized sound pressure level, at the receiving room and for each 100 to 3150 Hz frequency band). The reproducibility of the parameter *L'n,w* was calculated to be 2.3 dB with the individual laboratories performance z-scores varying up to 1.8. The laboratories z-scores for the reverberation time values were up to 2.4 (with a range of values of 4 s for the *RT* results at the frequency bands of 100 and 125 Hz). The *RT* values reproducibility was calculated to be from 0.1 s in the higher frequency bands to about 3 s in the very low frequency bands. The laboratories' z-scores for the normalized sound pressure level (*L'n*) were up to 2.6 (with a range of values of 8 to 12 dB in the frequency bands of 100 to 160 Hz). The reproducibility for these values was calculated to be from 1.8 to 6.3 dB. The measurement process is analyzed and the main conclusions are commented.

INTRODUCTION

To evaluate the confidence in the results of acoustic measurements is necessary to have the knowledge of the measurement uncertainties. An experimental method to estimate these uncertainties is based on interlaboratory comparisons. This consists in reproducing the measurements in similar conditions and then analysing the results using simple statistical tools to estimate the dispersion of results. The dispersion of the results among laboratories will provide a global uncertainty in conditions of reproducibility. Reproducibility is the closeness of agreement among repeated measurements under the same operating conditions over time or, in basic terms, is the variability introduced into the measurement system by the bias differences of different operators and their own methods.

METHOD

The interlaboratory comparisons reported in this paper concern the measurements of the *L'n,w* (weighted normalized impact sound pressure level, field measurements), of a concrete slab between two empty laboratory rooms within the Faculty of Engineering of the University of Porto. The 218 m^3 receiving room was adapted by including some sound absorptive materials and two pieces of furniture.

The goal was to analyse the variability of the results determined during the entire process of measurement of the *L'n,w*. The analyses were done according to the EN ISO 140-7:1998 and EN ISO 717-2:1996 and paying attention also to the EN 20140-2:1993 [1] and ISO 5725-2:1994 [2].

The interlaboratory comparative testing was done by single- or two-person measurement teams from fourteen Portuguese officially certified laboratories. The requirement of a minimum of eight teams stated in the EN 20140-2 [1] was fulfilled. Each measurement team used their equipment and their usual measuring procedure. No additional technical rules or suggestions were given by the host to the measurement teams other than the value of the receiving room's volume.

An alphanumeric code (1 to 14) was given to each laboratory for confidentiality purposes.

For each parameter to be analysed by statistical tools a "reference value" (or "conventional true value") was determined to be used in the comparison to each measured value. For this purpose the "mean" was chosen in all parameters except for the *L´n,w* where the "median" was used because it is not so affected by statistically suspect values (or outliers) [3] and because the values for this index cannot present decimals in accordance with the standard (chapters 3.1 and 4.3.1 of EN ISO 717-2:1996).

Each set of values for each parameter to be analysed by statistical tools**,** was previously checked for deviant values (technically invalid values or by the Grubbs' test for outliers - assumption: normality). No value was found to be suited to be taken out.

The distribution of the results was considered in accordance with the *t-student* distribution assuming for all parameters that the conditions for normality apply with degrees of freedom less than 30.

In this case the expanded uncertainty is based in the standard deviation multiplied by a coverage factor *k*. For a t-distribution with 13 degrees of freedom with a confidence level of 95%, *k* will be 2.16 (or 2.20 for *RT* due to a slightly smaller number of data) [4].

The variables chosen for statistical analyses were the 33 stated below:

RT - reverberation time at the receiving room (one for each 1/3 octave frequency band from 100 Hz to 3150 Hz);

L'n - normalized impact sound pressure level at the receiving room (average sound pressure level in the receiving room *Li* increased by 10*lg(A/10) a correction term related to a normalized equivalent sound absorption area of 10 m^2 (one for each 1/3 octave frequency band from 100 Hz to 3150 Hz);

L'n,w - weighted normalized impact sound pressure level (ISO 717-2).

STATISTICAL ANALYSIS

The results given by each laboratory were processed by statistical analyses. The basis for the evaluation was a standardized performance z-score calculated for each parameter and laboratory and defined as follows (higher z values indicate larger distance from the reference value):

$$z = \left| \frac{\text{measured value} - \text{reference value}^1}{\text{standard deviation}} \right|$$

[1] *mean* (or *median* for the *L'n,w*)

The interpretation of the z-scores is as follows:

$z < 0.5$	*excellent* approximation to the reference value;
$0.5 \le z < 1.0$	*good* approximation to the reference value;
$1.0 \le z < 2.0$	*fair* approximation to the reference value;
$2.0 \le z < 3.0$	*uncertain* (means that the measurements may be questioned and the laboratory must take measures to improve the quality of its work);
$z \ge 3.0$	*non-satisfactory* (means that the measurement results are unreliable).

RESULTS

The following tables and figures show the results as they were given by the laboratories, grouped by the three main intervening parameters (*RT*, *L'n* and *L'n,w*).

The figures 1 and 2 show the *RT* and *L'n* mean values measured by each laboratory. Very small variability is admissible among the *RT* results in each frequency band due to variability in the sound absorption in the receiving room introduced by the measuring team during measurements (for instance, one or two-persons team).

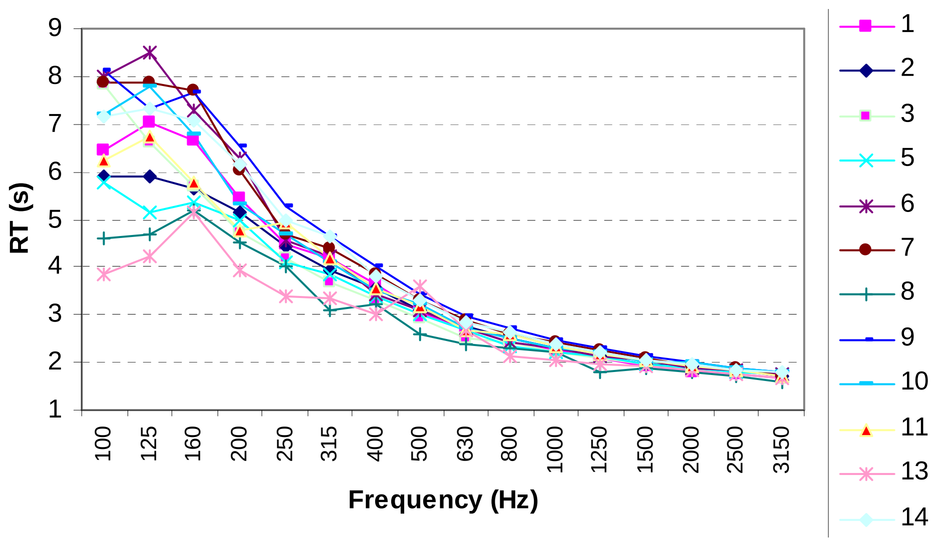

Figure 1 - RT values measured by each laboratory and frequency band

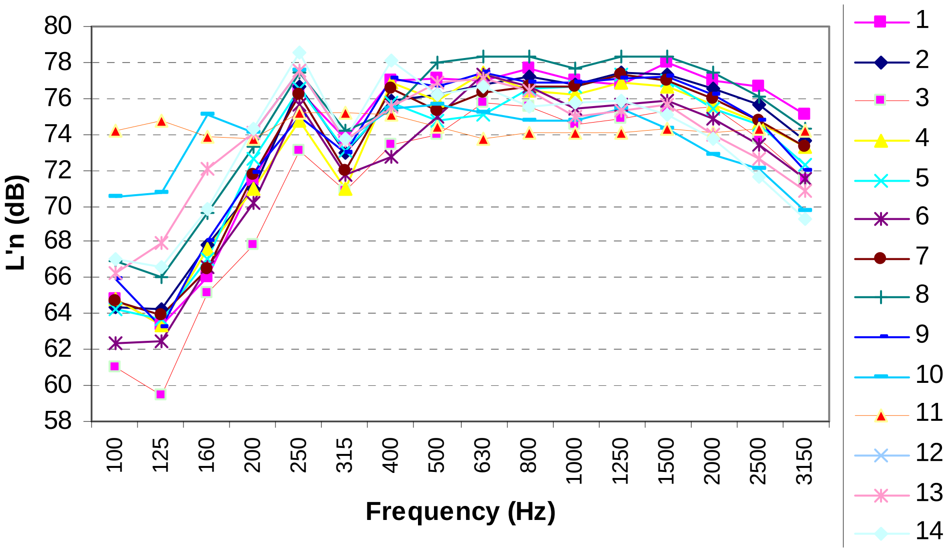

Figure 2 - L'n values measured by each laboratory and frequency band

Table 1 presents the *L'n,w* values calculated by each laboratory. Table 2 displays the basic statistical measures found for each parameter (*RT*, *L'n* and *L'n,w*).

Table 1 - L'n,w values given by each laboratory

Laboratory no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
L'n,w (dB/1/3 oct.)	82	82	80	82	81	80	82	83	82	81	83	80	83	82

Table 2 - Basic statistical measures for RT (s), L'n (dB) and L'n,w (dB)

Measure		minimum		mean		maximum		range (= max.-min.)		standard deviation	
Freq. (Hz)		RT	L'n	RT	L'n	RT	L'n	RT	L'n	RT	L'n
RT or L'n	100	3.9	61.0	6.6	65.2	8.1	71.6	4.3	10.6	1.4	2.5
	125	4.2	59.5	6.7	64.6	8.5	71.8	4.3	12.3	1.4	2.9
	160	5.2	65.1	6.4	68.2	7.7	72.6	2.6	7.5	0.9	2.2
	200	3.9	67.8	5.4	71.6	6.5	73.6	2.6	5.8	0.8	1.4
	250	3.4	73.1	4.5	75.7	5.3	77.6	1.9	4.5	0.5	1.5
	315	3.1	70.7	4.1	72.7	4.6	74.5	1.5	3.8	0.5	1.3
	400	3.0	72.7	3.6	75.7	4.0	77.7	1.0	5.0	0.3	1.4
	500	2.6	74.0	3.2	75.9	3.6	78.0	1.0	4.0	0.2	1.1
	630	2.4	75.0	2.7	76.8	3.0	78.3	0.6	3.3	0.1	1.0
	800	2.1	75.2	2.5	76.7	2.7	78.5	0.6	3.3	0.2	1.0
	1000	2.0	74.5	2.3	76.5	2.5	77.7	0.5	3.2	0.1	0.9
	1250	1.8	74.9	2.1	76.9	2.3	78.3	0.5	3.4	0.1	0.9
	1500	1.9	75.3	2.0	77.0	2.1	78.3	0.2	3.0	0.1	0.9
	2000	1.8	74.7	1.9	76.0	2.0	77.4	0.2	2.7	0.1	0.8
	2500	1.7	73.3	1.8	75.0	1.9	77.1	0.2	3.8	0.1	1.1
	3150	1.6	71.2	1.7	73.2	1.8	77.4	0.2	6.2	0.1	1.7
L'n,w (dB)		80		81.6 (82 median)		83		3		1.1	

Table 3 presents the performance z-scores for each laboratory and for each *RT* and *L'n* frequency band and *L'n,w*. The figure 3 displays the individual laboratories *L'n* performance z-scores for the frequency bands of 100 and 125 Hz.

Table 3 - Performance z-scores for RT, L'n and L'n,w for each laboratory and frequency band

Laboratory no.		1	2	3	4	5	6	7	8	9	10	11	12	13	14
z (RT)	100 Hz	0.1	0.5	0.9	-	0.6	1.0	0.9	1.4	1.1	0.4	0.3	-	2.0	0.4
	125	0.2	0.6	0.8	-	1.1	1.3	0.9	1.4	0.5	0.8	0.0	-	1.8	0.5
	160	0.3	0.8	0.2	-	1.1	0.9	1.4	1.3	1.3	0.4	0.7	-	1.3	0.7
	200	0.1	0.3	0.4	-	0.5	1.1	0.8	1.2	1.4	0.1	0.8	-	1.9	1.0
	250	0.1	0.2	0.4	-	0.9	0.1	0.3	1.0	1.5	0.4	0.8	-	2.2	0.9
	315	0.2	0.3	0.3	-	0.5	0.4	0.7	2.1	1.2	0.1	0.3	-	1.5	1.2
	400	0.3	0.0	0.4	-	0.5	0.5	1.1	1.3	1.7	0.2	0.0	-	1.9	0.9
	500	0.5	0.3	0.5	-	0.7	0.3	0.5	2.4	1.0	0.1	0.0	-	1.6	0.5
	630	0.3	0.1	1.2	-	0.5	0.2	0.9	2.3	1.4	0.3	0.4	-	0.5	0.8
	800	0.3	0.2	0.3	-	0.9	0.2	0.7	1.1	1.5	0.2	0.8	-	2.1	1.0
	1000	0.4	0.1	1.1	-	0.7	0.0	0.9	0.9	1.5	0.0	0.3	-	2.3	0.5
	1250	0.3	0.0	0.6	-	0.2	0.1	0.8	2.4	1.3	0.5	0.3	-	1.3	0.6
	1500	1.0	0.8	1.1	-	0.8	0.7	1.0	1.5	1.4	0.1	0.4	-	1.1	0.7
	2000	1.5	0.0	0.8	-	0.4	0.1	0.5	1.6	1.3	1.4	0.2	-	1.2	0.5
	2500	0.9	0.1	1.2	-	0.4	0.2	0.7	1.9	0.9	1.4	0.1	-	1.3	0.0
	3150	0.7	0.2	1.4	-	0.3	0.1	0.2	2.2	1.1	1.1	0.6	-	0.7	0.7
z (L'n)	100 Hz	0.2	0.3	1.7	0.2	0.4	1.1	0.2	0.7	0.3	1.0	2.6	0.1	0.3	0.5
	125	0.4	0.1	1.8	0.4	0.3	0.7	0.3	0.5	0.5	1.0	2.5	0.2	0.9	0.4
	160	1.0	0.2	1.4	0.3	0.5	0.7	0.8	0.6	0.1	2.0	1.6	0.4	1.0	0.7
	200	0.1	0.4	2.7	0.4	0.7	1.0	0.1	1.2	0.1	0.4	0.5	0.0	1.4	0.2
	250	0.5	0.6	1.7	0.7	0.6	0.0	0.4	1.2	0.5	0.4	1.3	1.6	1.3	0.9
	315	0.9	0.3	1.5	1.4	0.3	0.8	0.5	1.2	0.3	0.2	1.5	1.6	0.9	0.1
	400	0.9	0.1	1.7	0.8	0.0	2.2	0.5	0.3	1.0	0.2	0.5	0.1	0.3	1.4
	500	1.1	0.3	1.7	0.0	1.0	0.8	0.5	2.0	0.8	0.1	1.0	0.5	0.8	0.5
	630	0.2	0.0	1.0	0.6	1.6	0.5	0.5	1.5	0.6	0.5	1.7	0.3	1.5	0.7
	800	1.0	0.5	1.2	0.3	0.2	0.1	0.1	1.6	0.2	0.4	1.3	1.5	1.8	0.0
	1000	0.6	0.4	2.2	0.3	0.2	1.2	0.3	1.4	0.5	0.0	0.7	1.1	1.0	1.1
	1250	0.1	0.5	2.1	0.0	0.4	1.3	0.4	1.5	0.2	0.5	0.9	1.1	1.0	0.9
	1500	1.1	0.4	1.8	0.3	0.0	1.2	0.0	1.5	0.3	0.4	0.3	1.3	1.5	0.5
	2000	1.2	0.6	0.6	0.5	0.8	1.4	0.0	1.7	0.2	0.9	0.8	1.6	1.0	0.4
	2500	1.4	0.6	1.0	0.3	0.4	1.4	0.1	1.0	0.2	0.1	1.9	1.5	0.6	0.5
	3150	1.2	0.3	1.0	0.1	0.5	1.0	0.1	0.7	0.7	0.3	2.5	1.2	0.4	0.5
z (L'n,w)		0.0	0.0	1.8	0.0	0.9	1.8	0.0	0.9	0.0	0.9	0.9	1.8	0.9	0.0

Laboratories no. 4 and 12 did not present their *RT* data

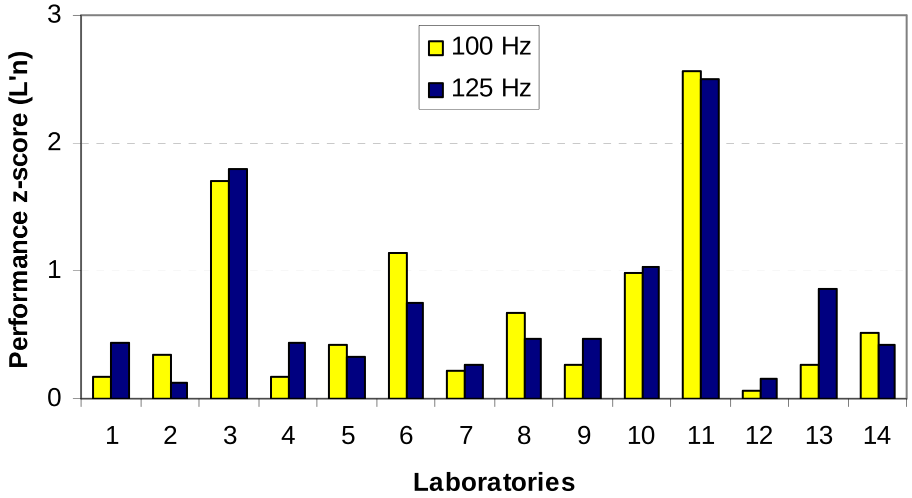

Figure 3 - Performance z-scores for L'n at 100 Hz and 125 Hz (see Table 3).

Uncertainty and Reproducibility

Table 4 presents the uncertainties for a confidence level of 95%, which can be understood as the reproducibility (*R*) for each parameter: $R_i \approx k \cdot s_i$ where *k* is the coverage factor (= 2.16, or 2.20 for *RT*) and s_i the standard deviation for parameter *i*.

The figures 4 and 5 display the *RT* and *L'n* values with 95% confidence intervals that represent the reproducibility *R*.

Table 4 - Calculated reproducibilities (R)

Freq. (Hz)	100	125	160	200	250	315	400	500	630	800	1k	1250	1.5k	2k	2.5k	3150
R (RT) (s)	3.0	3.1	2.1	1.7	1.1	1.0	0.6	0.5	0.3	0.4	0.3	0.3	0.2	0.1	0.1	0.1
R (L'n) (dB)	5.4	6.2	4.8	3.0	3.2	2.7	3.0	2.3	2.2	2.1	1.9	2.0	1.9	1.8	2.4	3.6
R*	7	6	5.5	5	5	5	5	5	5	5	4	4	5	6	7	7
R(L'n,w)(dB)	2.3															

* ISO 140-2 values (table A.3) by 7 UK laboratories on 1978 (on wooden pavement)

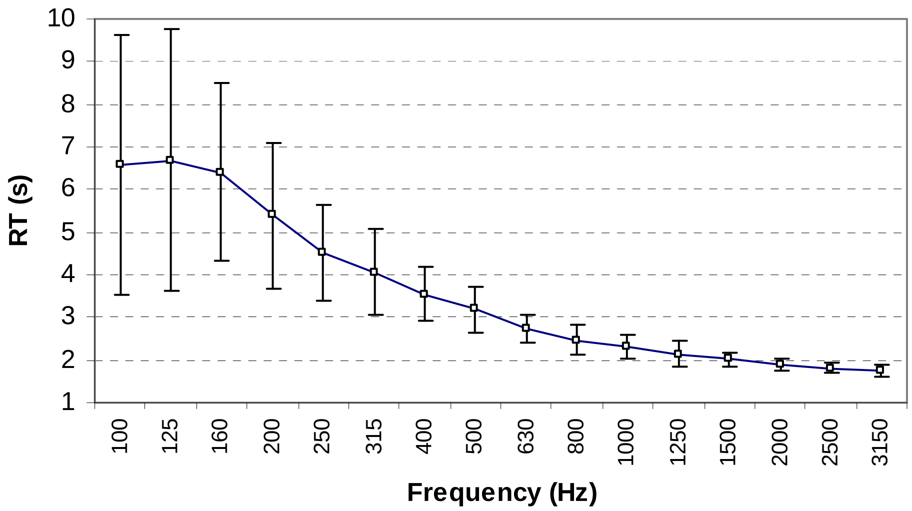

Figure 4 - RT mean values with a 95% confidence interval (≈ reproducibility R)

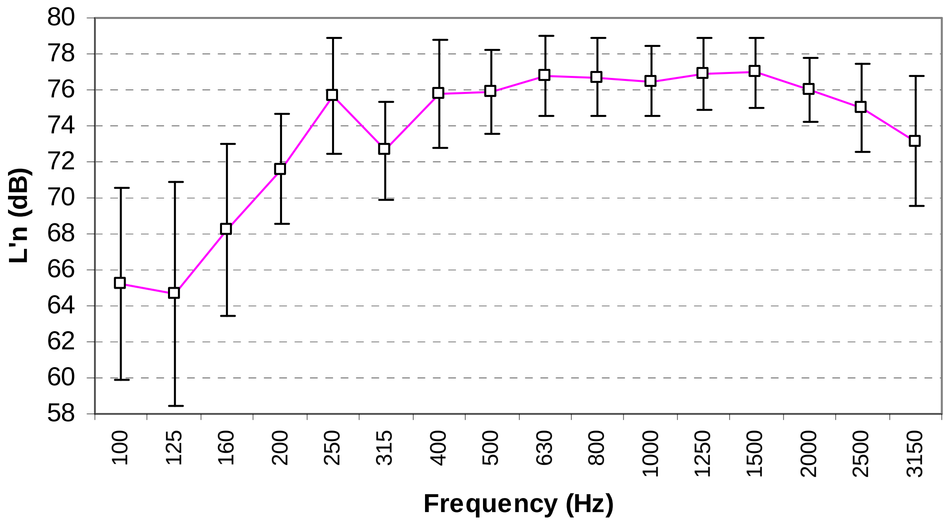

Figure 5 - L'n mean values with a 95% confidence interval (≈ reproducibility R)

CONCLUSIONS

The values measured for the *L'n,w* show a large variability (a 3 dB range) with a predicted reproducibility of 2.3 dB. This large reproducibility value and some individual laboratories *L'n,w* performance z-scores (varying up to 1.8) raise some pertinent questions about the usual trueness that the laboratories want to transmit to their clients and even to the authorities about their work.

That value is nevertheless similar to the "safety margin" that some authors support for this parameter as Simmons in Sweden after analyses with 17 laboratories [5]. Also the standard ISO 140-2 refers (annex B.2) that in laboratory conditions the reproducibility will be usually about 1 to 3 dB. In field situations, the values will be, at least, the same. That reproducibility is also close to the 3 dB presented on the Portuguese Building Acoustics Noise Code [6] as the legal uncertainty to state for this parameter.

The *L'n,w* standard deviation of 1.1 dB is very close to the one referred by Gerretsen when analyzing Dutch reports [7].

For all these, this work can support that an uncertainty of 2 dB should be stated when presenting each and every *L'n,w* result.

Concerning the intermediate parameter *RT* it must be pointed out the large deviation from the reference values shown at very low frequency bands (with a 4-second range for the *RT* values at 100 and 125 Hz frequency bands). The individual laboratories z-scores for the *RT* values were from 0 to a maximum of 2.4 that represents a questionable work. The *RT* values reproducibility was calculated to be from 0.1 s in the higher frequency bands to about 3 s in the very low frequency bands (100 and 125 Hz).

The variability for the normalized impact sound pressure level (*L'n*) showed a very wide range of values from 8 to 12 dB in the 100 to 160 Hz frequency bands.

The individual laboratories z-scores were from 0 to 2.6 and the reproducibility was calculated to be from 1.8 dB (at 2 kHz) to 6.2 dB (at 125 Hz).

However, the reproducibility for the impact sound pressure levels are similar (or 0.1 to 0.6 dB lower) to the ones referred by Kylliäinen in Finland done with 50 concrete slabs [8]. The reproducibility for the *L’n* is, for all frequency bands except one, below the values stated in the ISO 140-2 standard as an informative annex. The *R*-values of 5 and 6 dB determined for the *L’n* very low frequency bands (lower than 200 Hz) force to issue a strong advice to handle carefully the measurements in these situations. The *L’n* reproducibility of 2 to 4 dB at the 1250 to 3150 Hz frequency bands have a higher risk for the final *L'n,w* result because the adjustment done in the ISO 717-2 method is affected by small variations of the *L’n* in at least one higher frequency band. In the tested situation a change of 1 dB in just one value of *L'n* on frequency bands above 1000 Hz may induce a variation of 1 dB in the final *L’n,w*.

This large variability of measurements results, mainly in very low frequency bands, will be minimized in the majority of situations where the receiving room's volume is smaller than the one at these comparisons and/or with a larger sound absorption. The situation used in these measurements aimed to enlarge the hazards of some extreme situations (rooms a little bit larger than the common dwelling living rooms and without furniture or just after construction).

The uncertainty can be minimized if special care and attention is put on measuring *RT* and *Li*, especially below 250 Hz. In these frequency bands, at least, a minimum of six measurements, evenly spatially dispersed within the room (eight if the receiving room is large and without furniture) should be used and any aberrant value (statistically outlier) ought to be ignored. If possible, increased sound absorption should be set in the receiving room and also some scattered elements (like large furniture) to improve the diffusibility of the installed sound field.

REFERENCES

[1] EN 20140-2:1993 Acoustics - Measurement of sound insulation in buildings and of building elements - Part 2: Determination, verification and application of precision data (ISO 140-2:1991).

[2] ISO 5725-2:1994 Accuracy (trueness and precision) of measurement methods and results - Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method.[3] Maurice G. Cox - "The evaluation of key comparison data", Metrologia, **39,** 589-595 (2002).

[4]Technical Report EA-4/16 - EA Guidelines on the expression of uncertainty in quantitative testing, 16-17, European Co-operation for Accreditation (2003).

[5] Christian Simmons, Uncertainty of Measured and Calculated Sound Insulation in Buildings - Results of a Round Robin Test, Proceedings “Managing Uncertainty in Noise Measurement and Prediction”, Le Mans, France (2005).

[6] "Regulamento dos Requisitos Acústicos dos Edifícios" (Building Acoustics Noise Code - in Portuguese), Law D.L. n. 129/2002 of May 11, Lisbon (2002).

[7] E. Gerretsen, Interpretation of uncertainty in acoustic measurements in buildings, Proceedings “Managing Uncertainty in Noise Measurement and Prediction”, Le Mans, France (2005).

[8] Mikko Kylliäinen, Standard deviation in field measurements of impact sound insulation at enlarged frequency range from 50 to 3150 Hz, Proceedings “Managing Uncertainty in Noise Measurement and Prediction”, Le Mans, France (2005).